4^{th} International Symposium on Innovative Approaches in Engineering and Natural Sciences

Proceedings

4^{th} International Symposium on Innovative Approaches in Engineering and Natural Sciences

Samsun / Turkey

November 22-24, 2019

4th International Symposium on Innovative Approaches in Engineering and Natural Sciences

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Typesetting

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ISBN: 978-605-81988-8-3

Published by SETSCI

Publication Date: December 15, 2019

SETSCI conference proceedings
SETSCI Conference Proceedings
4 (6), 289-315, 2019

4th International Symposium on Innovative Approaches in Engineering and Natural Sciences

November 22-24, 2019, Samsun, Turkey

https://doi.org/10.36287/setsci.4.6.080
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ISAS ENS WINTER - 2019

Stratigraphy and Petrographical Properties of the Kazdağ Massif Metamorphites in the North of Güre-Çamlıbel, Edremit-Balıkesir-Turkey

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Presentation/Paper Type: Oral / Full Paper

Abstract – The study area covers Kaz Mountain and its surroundings which is located in the north of Güre, Çamlıbel and Arıtaşı Neighborhoods of Edremit District of Balıkesir Province. The Kazdağ Massif which is estimated to be of Paleozoic primitive age starts with the Fındıklı formation in the lower part. This formation is composed of hornblende gneiss, biotite-hornblende gneiss, epidote-hornblende gneiss, epidote-biotite gneiss, garnet-biotite gneiss, garnet-hornblende gneiss, disten-garnet-mica schist and disten-garnet-biotite schist which show alternation with crystallized limestones (Altınoluk marble member). In the upper part of the Fındıklı formation, there are crystallized limestones (Babadağ marble member). Tozlu formation which is tectonically overlain Fındıklı formation consists of amphibolite – amphibole schist (amphibolite member), metadunite – metaproxenite – metaproxenhornblendite - serpentinite (metaophiolite member) and crystallized limestones (marble member) with lateral-vertical transition with each other. Sarıkız formation is observed with an unconformity on Tozlu formation. Sarıkız formation starts with the thin gneiss level in the lower part, and upwards, higher up pass into thick crystallized limestones with calcschist interlevels. In the upper part Sütüven formation which is observed tectonically is composed of mica gneiss - sillimanite-biotite gneiss - hornblende-biotite gneiss including granitic gneiss (granitic gneiss member) - amphibolite - marble bands and lenses. The anatexis ve migmatite is sometimes observed in Sütüven formation.

The mineral assemblage which consist of *hornblende (tschermakite, edenite and barroisite) + plagioclase (albite-oligoclase-andesine) + quartz ± orthoclase + biotite (brown, green) + garnet (prop-almandine-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, penninite-clinochlore) ± kyanite ± staurolite + muscovite ± calcite ± sillimanite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite* are observed in amphibole gneisses and biotite gneisses which constitute the dominant lithology of Fındıklı formation. The disten-garnet-mica schist and disten-garnet-biotie schist which are observed in the upper part of fındıklı formation show the mineral assemble which consist of *biotite (brown) + quartz + garnet (prop-almandine-grossular) + kyanite + sillimanite + plagioclase (albite-oligoclase-andesine) ± muscovite + chlorite (ripidolite-picnochlorite, penninite-clinochlore) ± epidote ± zoisite / clinozoisite + orthoclase + tourmaline (green) ± sphene ± rutile ± apatite*.

The mineral assemblage which consist of *plagioclase (albite-oligoclase-andesin) + quartz ± orthoclase + biotite (brown and green) ± sillimanite + hornblende (tschermakite) ± garnet (prop-almandine-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, penninite-clinochlore) + muscovite ± kyanite ± calcite ± staurolite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite* are observed in mica gneiss, sillimanite-biotite gneiss and hornblende-biotite gneiss which constitute the dominant lithology of Sütüven formation. The amphibolites which are located as interlevels in this formation are evident with the mineral assemblage which consist of *hornblende (tschermakite) + plagioclase (albite-oligoclase-andesine) ± biotite (brown) ± quartz ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, penninite-clinochlore) + sphene*. The granitic gneisses belonging to Sütüven formation show the mineral assemblage which consist of *plagioclase (albite-oligoclase-andesine) + orthoclase + quartz + biotite (brown) ± hornblende (tschermakite) + garnet (prop-almandine-grossular) ± chlorite (ripidolite-picnochlorite, penninite-clinochlore) ± epidote ± zoisite / clinozoisite + sphene ± rutile ± apatite*.

That both the mineral paragenesis in different metamorphism conditions is observed in the metapelitic-metasemipelitic-metabasic rocks which are located in especially the Fındıklı and Sütüven formations of the Kazdağ Massif and this massif has exposed to metamorphism with multi-stage as a result of dense tectonic movements indicate that this massif has undergone metamorphism of least three stage.

Keywords – Güre-Çamlıbel (Edremit-Balıkesir), Kazdağ massive, Stratigraphy-petrography, High pressure - high temperature metamorphism. Deformation-metamorphism relationship

I. Introduction

The study area covers to Kaz Mountain and its surroundings located the north of Güre, Çamlıbel and Arıtaşı Neighborhoods of Edremit District (Balıkesir) (Figure 1). In this study, it is aimed to determine the stratigraphic properties of the Kazdağ Massif metamorphites exposed in the region and to investigate the petrographic properties of these metamorphites exposed to polymetamorphism.

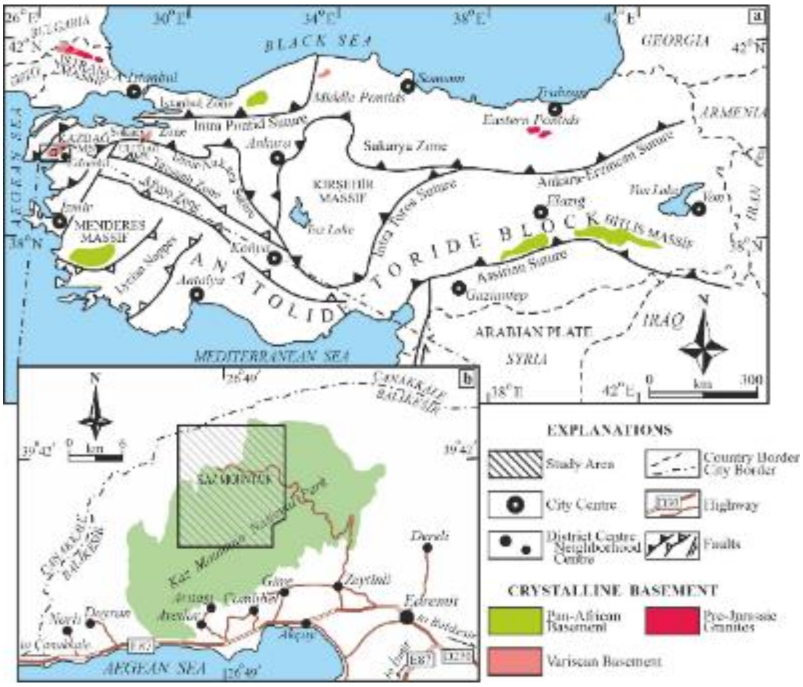

Fig. 1. a) The Tectonic Units of Turkey and the crystalline basements [4], b) the map of the study area

The study area is observed in Pontides Tectonic Unite Pontides which is one of Turkey's tectonic belts [1], The study area is observed on the bottom of Sakarya Continent within the Pontides [2] and [3] and in the Kazdağ Massif which extends as a tectonic window [3] (Figure 1).

The first detailed geological map in the Kazdağı region was made by [5]. Reference [6] stated that the metamorphic rocks in the north of Kazdağ consist of green schists, mica schists, gneisses and marbles developed in the albite-epidote schist facies. Reference [7] said that the metamorphic rocks in the Kazdağı region include hornblende-biotiteuartz-plagioclase gneisses, quartz-hornblende-plagioclase gneisses containing garnet, marbles, hornblende schists, albite-hornblende-chlorite schists, diopside schists, tremolite proxenites, orthogneisses and olivine schists. Reference [8] stated that the Kazdağ gneiss massif is a core formation at approximately a spread of 45 km and a width of 15 km in the NE-SW direction. He said that Paleozoic aged schists in the region cover the gneisses unconformably and all these units were cut by Paleozoic aged granodiorite. He stated that schists and gneisses with the effect of granodiorite show a high-grade metamorphism effect, especially near the contact. The researcher said that the gneisses in the region are composed of biotite-plagioclase gneiss, diopside-amphibole gneiss, epidote gneiss, sillimanite-biotite gneiss and biotite-muscovite gneiss, in addition, that garnet-amphibolite, tremolite fels, pyroxenite, enstatite-serpentinite, olivine schist, and muscovite-quartzite are exposed in the region. Reference [9] suggested that the metamorphic rocks observed in the region are of Silurian-Devonian age. He stated that the Permian aged granodiorite cut the metamorphic sequence in the region and that the skarn zones developed. Reference [1] included the metamorphics in the Kazdağı region within the tectonic unit which he defined as the Pontides.

References [10] and [11] claimed that the Kazdağ metamorphites are in the dom structure and that these consist of metadunite, metagabbro-pyroxenite, amphibolite, paragneiss, marble and epimetamorphic schists from bottom to top and that these undergo metamorphism in greenschist and amphibolite facies at middle pressures. Reference [12] described the metamorphic rocks covered by Karakaya Complex as Kazdağ Massif in the region. They claimed that the gneisses, amphibolites and marbles that form the core of Kazdağ have been cut by Late Tertiary aged granodiorite. They described the units in the region according to young from old as Tozlu formation consisting of serpentinized dunites, amphibolites and layered metagabbros and as Bozağaç Hill formation consisting of gneisses and as Sarıkız formation made of marbles. Reference [13] stated that the units which termed as the Kazdağ Group in the region undergo metamorphism in amphibolite and greenschist facieses. They claimed that the amphibolite facies consisted of migmatite, sillimanite-staurolite gneiss, biotite gneiss, biotite-amphibole gneiss, amphibole gneiss and that micaceous quartz schist, marble, muscovite-calcschist, sericite-muscovite-quartz schist, epidote-actinolite-chlorite schist, tremolite-actinolite-serpentinite, phyrophyllite-calcschist, biotite-chlorite schist, quartz-muscovite-sericite schist, metaclays, marble, phyllite, graphite schist, epidote-chlorite-actinolite, quartz-epidote-chlorite schist, epidot-muscovite-albite-chlorite schist ve quartz schist were observed in greenschist facies. Reference [14] suggested that the gneisses in the Kazdağ massif contain staurolite, kyanite and silimanite and the massif undergoes metamorphism in the amphibolite facies. He also stated that metaophiolites are present in the region and they undergo metamorphism in amphibolite facies.

According to [3], the Kazdağ Group outcrops as a tectonic window on the basis of the Sakarya continent. The researchers stated that the Kazdağ Group was tectonically covered by the Karakaya Complex in the east and by the Late Cretaceous aged Çetmi Ophiolite Melange in the west and north, and that the Kazdağ Group had a structural thickness over 10 km. Reference [15] determined 304±16 million years of age in gneisses and amphibolites belonging to Kazdağ Massif. They stated that this age corresponded to the age of the first metamorphism. They also suggested that these rocks undergo metamorphism at a pressure of 5±1 kbar and a temperature of 340±20 ºC. Accordingly, they determined the age of metamorphism as Middle Carboniferous. Reference [16] determined the second age of metamorphism in the Kazdağ Massif. The researchers stated that these rocks are 22 ± 2 million years old and undergo second metamorphism at 4±1 kbar pressure and 650±20 ºC temperature according to the determination of the age in which they determined gneiss. They suggest that the massif is 15 km deep and has reached its present position since Oligo-Miocene in the last metamorphism conditions of Kazdağ metamorphics.

Reference [17] suggested that the Kazdağ Massif is an anticlinorium dipping in both directions. Kazdağ Massif metamorphics are classified as Fındıklı formation, Tozlu formation, Sarıkız Marble and Sütüven formation from bottom to top by they. According to the researchers, the Kazdağ Massif has gained its present position by rising in the dom view as a metamorphic core complex with the detachment and lateral slip faults developed after Miocene. Reference [18] stated that the metaophiolites in the Kazdag massif contains 10-20% TiO_2 and that there are a few million tons of titanium reserves in the region. Reference [19] stated that there are metaultramafics, whose internal structure are regular, and banded metagabbros belong to the oceanic crust in bottom of the Kazdağ metamorphic sequence, and that these cumulated metagabbros are geochemically oceanic crust origin. They argue that this oceanic crust is unconformably covered by a platform sequence and that the platform sequence starts with a base conglomerate derived from the oceanic crust and that higher up the sequence passes to thick white marble and that the sequence continues with metaclastic rocks at the top. The researchers said that this platform sequence undergoes metamorphism up to migmatization and that syntectonic granites are settled in the platform sequence.

Reference [20] stated that metagabbros observed in metaophiolitic rocks belonging to Kazdağ massif undergo metamorphism under ~ 660 ºC and ~ 10 kbar pressure conditions. The researcher states that the metaophiolitic rocks are separate tectonic slices indicated higher pressure within the Kazdağ Massif. The researcher argues that the amphibolite facies metamorphism arises from the subduction under the Sakarya Zone towards the north of the İzmir-Ankara branch of the Neo-Tethyan ocean.

II. Materials and Method

This study was conducted by [21] using the project numbered 10201139 supported by Selçuk University Scientific Research Projects Coordination Unit. Field studies were carried out on the top of the topographic map sheets of Ayvalık - İ 17-c1 and İ 17-c2, which are 1/25000 scaled, on the basis of drawing the boundaries and linear-planar structures of the units in the region. In this context, detailed geological map of the study area was prepared by using the geological map prepared by [18] (Figure 2). The stratigraphic cross section of the region was made by considering the up-down relationship of the lithologies in the study area (Figure 3). Thin sections of 105 rock samples collected during field studies were made in Konya Technical University Faculty of Engineering and Natural Sciences, Geological Engineering Department Thin Section Laboratory. The metamorphism properties and metamorphism-deformation relations of these samples was discussed under the Nikon brand polarizing microscope according to mineralogical composition, texture-structure properties, mineral paragenesis and index minerals.

In the nomenclature of “gneisses”, “amphibolites” and “mica schists” from metamorphic rocks, classification diagrams of low and high temperature metamorphic rocks of [22] were used. “Serpentinites” have been named by considering rock structures and the percentages of their components. It has been observed that the rocks called as “metadunite”, “metaproxenite” and “metaproxenhornblendite” are metamorphosed and in contrast that these rocks protect the origin rock textures. These rocks was named as “gabbro”, “dunite”, “proxenite” and “proxen-hornblendite” by considering the mineralogical compositions and texture-structure characteristics of these rocks. “Meta-” prefix indicating that they undergo metamorphism was added at the beginning of these nomenclatures. In the study area, massive metamorphic rocks rich in carbonate minerals were named as “crystallized limestone”. The separation of calcite and dolomite minerals in these rocks was done according to their optical properties in the polarizing microscope and especially with the aid of alizarin test applied to these rocks.

III. Stratigraphy and Petrography

The Kazdağ Massif is a unit that consist of completely metamorphic rocks which crops out in the central sections of the Kazdağ Mountains extending between Edremit Gulf in the south and Yenice and Bayramiç (Çanakkale) in the north.

The base and upper limit of the Kazdağ Massif cannot be observed in the study area. The massive outcrops under the Karakaya Complex in northwestern Anatolia in the form of tectonic windows [17]. According to [17], the Kazdağ Massif has a tectonic contact with Permian-Miocene aged lithologies from the top. It is also unconformably overlain by Pliocene aged units. According to [3], Triassic – Miocene aged units are observed on the Kazdağ Massif with tectonic contact.

Datas on the primary age of the Kazdağ Massif are not yet available. In contrast, [12] and [23] stated that the first metamorphism age of the Kazdağ Massif is the Early Carboniferous by the Rb-Sr and the K-Ar methods. Reference [15] indicate that the age of the first metamorphism in the massif is 304±16 my (Middle Carboniferous). The last metamorphism age in the massif is suggested as Oligo-Miocene [12], [16] and [23]. Therefore, the primary sedimentation age of the metamorphites in the Kazdağ Massif should be Paleozoic (pre-Carboniferous).

The last metamorphism conditions of the Kazdağ metamorphites indicate that the massif is 15 km deep and that it has gained its present position by rising in the form of domes with detachment and lateral slip faults surrounding it since Oligo-Miocene [16]. According to [17], the rise of the Kazdağ Massif is post-Miocene. The researchers argue that the rise of the massif is still continuing due to the active faults around the Kazdağ Massif. The structure of the Kazdağ Massif is in the form of an anticlinorium with a fold axis in NE-SW direction and dipping in both directions [17].

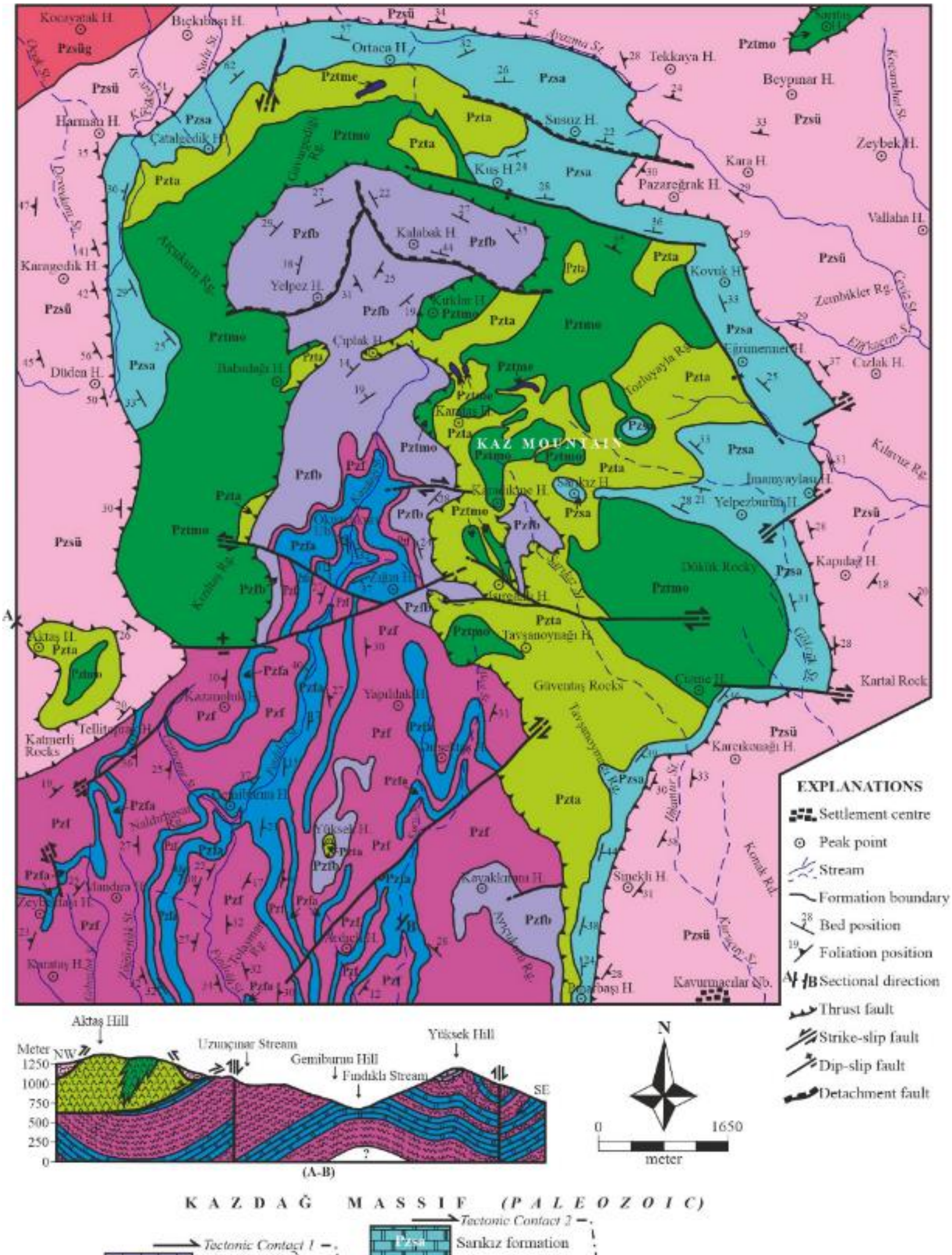

Fig 2. The geological map of the study area (partially modified from [18])

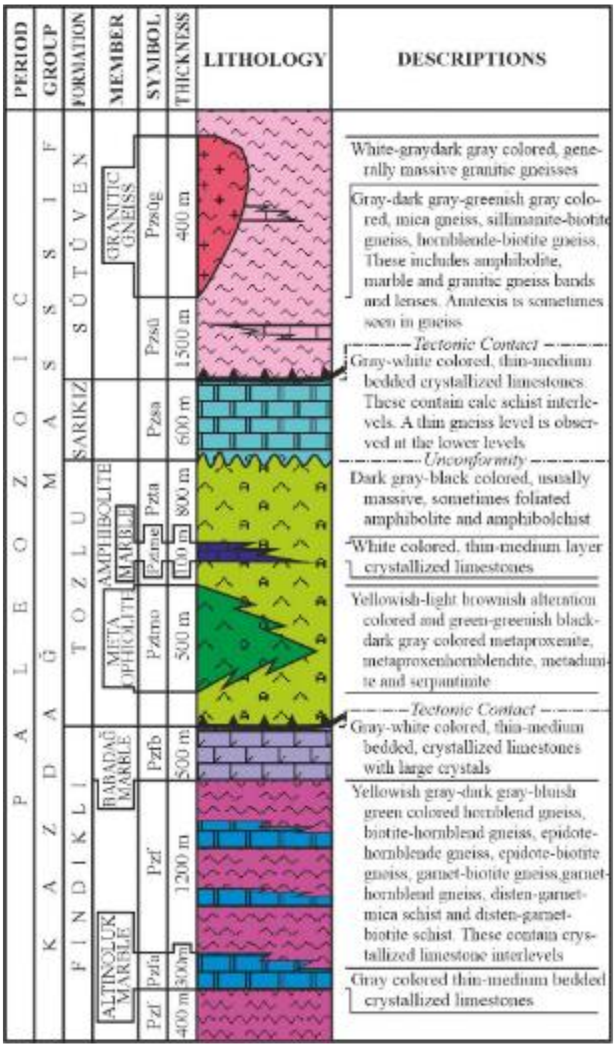

Fig. 3. The tectono-stratigraphic cross section of the study area (partially revised from [17])

A. *Fındıklı Formation*

Definition and spread

The dominant lithology of the Fındıklı formation located in the core of the Kazdağ Massif consists of hornblende gneisses, biotite-hornblende gneisses, epidote-hornblende gneisses, epidote-biotite gneisses, garnet-biotite gneisses, garnet-hornblende gneisses, kyanite-garnet-mica schists and kyanite-garnet biotite schists. These amphibole gneisses, biotite gneisses, mica schists and biotite schists show alternation with crystallized limestones (Altınoluk marble member) whose thicknesses show quite variability. At the top level of the Fındıklı formation, there are coarse crystalline crystallized limestones (Babadağ marble member).

References [10], [11] and [12] included these amphibole gneisses in the amphibolite member of Tozlu formation. These lithologies was named as Fındıklı formation according to Fındıklı Stream in the study area by [17]. Fındıklı formation outcrops around Fındıklı Stream, Karataş Hill, Ardıçlı Hill, Zeybektaşı Hill, Mandıra Hill, Kazanoluk Hill and Yapıldak Hill in the southwest of the study area (Figure 2).

Lithology and petrography

The gneisses in the Fındıklı formation are very hard. The amphibole gneisses showing medium-coarse grains exhibit very distinct foliation (Figure 4-a). The hornblende and sometimes biotite elongated in a direction commonly observed in the rock forms this foliation, which is observed in the form of layering due to composition. Hornblendes are long prismatic, and biotites are typical with their platy forms, of these mafic minerals, characterized by their black colors. Amphibole gneissesin the unit contain crystallized limestone interlevels (Figure 4-b). They also presents alternation with crystallized limestones that form to Altınoluk marble member of Fındıklı formation. The gneisses in the Fındıklı formation are darker in color than the Sütüven formation. In addition, they are separated from the gneisses of Sütüven formation as they contain widely amphibole.

Hornblends are commonly observed at all levels of the Fındıklı formation. Hornblende and epidote are common in the gneisses in the bottom levels of the Fındıklı formation, on the other hand, hornblende, biotite and garnet are common in the gneisses in the middle levels of the Fındıklı formation, also, hornblende, quartz and feldspar in the gneisses in the upper levels of the Fındıklı formation. Garnets observed in gneisses and micaschists belonging to Fındıklı formation are distinctive with their brown-black colors and prismatic shapes. The diameter of garnets sometimes reaches up to 1 cm.

Kyanite-garnet-mica schists and kyanite-garnet-biotite schists observed in the Fındıklı formation are characterized by gray-dark gray colors and schistosity structures (Figure 5-a). These metapelitic schists are observed in the upper levels of the Fındıklı formation.

The flaser gneisses are observed sometimes in the Fındıklı formation. Flaser structures in these rocks consist of feldspar crystals (Figure 5-b). There is the thin quartz schist level in the upper levels of the Fındıklı formation. Quartz schists are yellowish gray colored, very distinct schistosity and easily brittle.

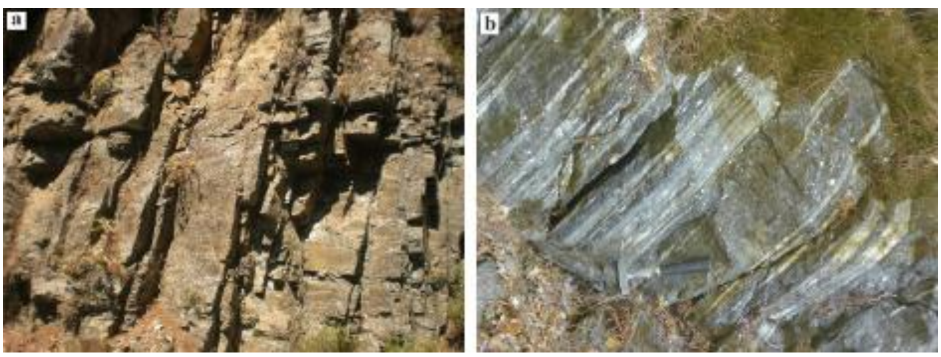

Fig. 4. a) Hornblende gneisses observed on the eastern slope of Fındıklı Stream in south of Gemiburnu Hill, b) Biotite-hornblende gneisses with crystallized limestone interlevels (white colored levels) found in Fındıklı Stream

Fig 5. a) Kyanite-garnet-biotite schists located north of Gürlek Hill, b) Hornblende gneisses with flaser structure observed in Fındıklı Stream

Crystallized limestone levels up to 0.5 m in thickness are observed in the gneisses containing amphibole, which constitute the dominant lithology of the Fındıklı formation (Figure 4-b). In amphibole gneisses and these marble interlayers, there are very often folded structures, flat folds and z-folds due to tectonic movements. Flow structures are observed in amphibole gneisses at south of Gemiburnu Hill, which is located to the south of the study area.

Fabric and mineralogy

The **amphibole and biotite gneisses** commonly observed in the Fındıklı formation consist of hornblende gneisses, biotite-hornblende gneisses, epidote-hornblende gneisses, epidote-biotite gneisses, garnet-biotite gneisses and garnet-hornblende gneisses. *Hornblende (tschermakite, edenite and barroisite) + plagioclase (albite-oligoclas-andesine) + quartz ± orthoclase + biotite (brown, green) + garnet (prop-almandine-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, pennin-clinochlorine) ± kyanite ± staurolite + muscovite ± calcite ± sillimanite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite* are observed in these amphibole and biotite gneisses. These rocks are characterized by porphyroblastic, granonematoblastic and granolepidoblastic textures.

The **mica schists and biotite schists** observed at the upper levels of the Fındıklı formation consist of kyanite-garnet-micaschist and kyanite-garnet-biotitechists. *Biotite (brown) + quartz + garnet (prop-almandine-grossular) + kyanite + sillimanite + plagioclase (albite-oligoclas-andesin) ± muscovite + chlorite (ripidolite-picnochlorite, pennin-clinochloride) ± epidote ± zoisite / clinozoisite + orthoclase + tourmaline (green) ± sphene ± rutile ± apatite* is observed in these metapelitic rocks. These rocks are characterized by porphyroblastic, lepidoblastic and granolepidoblastic textures.

Hornblende; is commonly tschermakite, locally edenite and a small amount of barroisite. It is commonly observed especially in hornblende gneisses. ***Barroisites*** are prismatic in shape, sometimes pale, often pronounced bluish green in color and low angled oblique extinction ranging from 18° to 22°. ***Edenites*** are green-dark green in color and have a low angled oblique extinction between 21° and 23° and are prismatic in shape. Edenites and barroisites are observed in some hornblende gneisses as inclusions extending in one direction forming S1 foliation within plagioclase porphyroblasts. Edenites and barroisites are incompatible with the S_2 foliation formed by the tschermakites surrounding the plagioclase porphyroblast. Therefore, these edenites and barroisites that make up the S_1 foliation are the first stage metamorphism product occurring in conditions reaching from the epidote-amphibolite facies to the amphibolite facies, in the metamorphism, temperature is low and pressure is high [21].

Another amphibole mineral commonly observed in amphibole gneisses is ***tschermakite***. Tschermakites are generally long prismatic in shape and brownish green in color. They show oblique extinction between 17^o-21^o. Tschermakites are in the form of long prismatic crystals arranged parallel to S_2 foliation in amphibole gneisses (Figures 6-a and b). In particular, epidote porphyroblasts surrounded by S_2 foliation in epidote-hornblende gneisses have been transformed tschermakite with progressive reactions from the edges (Figures 6-b, c and d). Therefore, the tschermakites observed in amphibole gneisses should be exposed under the conditions of high temperature upper amphibolite facies observed as second stage metamorphism in the Kazdağı Massif together with the increase in temperature [21]. Tschermakites have been turn to chlorite from the crystal edges by the reactions that regressive as a result of the last metamorphism observed in the Kazdağ Massif.

Micas*;* The especially biotites than micas is more common in amphibole and biotite gneisses, mica schists and biotite schists. Muscovite is observed in secondary amounts. ***Biotites*** are platy-shaped and brown-green in color (Figure 7). The brown biotites were aligned as parallel both to the S_1 foliation plane together with epidote, edenite and zoisite / clinozoisite and to the S_2 foliation plane together with muscovite, tschermakite and kyanite (Figure 7). Therefore, they are formed under amphibolite facies conditions. The biotites turned to sillimanite and kyanite by progressive metamorphism and partly or completely chlorite (ripidolite-picnochlorite) by regressive metamorphism. ***Muscovites*** are characterized by its plate-like shapes and flat extinction. They turned to sometimes sillimanite and kyanite by progressive metamorphism in mica schists.

Feldspars; are observed as plagioclase and orthoclase in amphibole gneiss, biotite gneiss and metapelitic rocks (Figures 6-a, 7 and 8). ***Plagioclases*** are sometimes observed as porphyroblasts, and as sometimes smaller sized and as generally subidioblastic-xenoblastic crystals. Hornblende (mostly edenite and barroisite), garnet, brown colored biotite, epidote, quartz and opaque mineral inclusions are observed in plagioclase porphyroblasts. The extending in one direction brown biotite, edenite, chlorite, barroicite and epidote inclusions form the foliation plane of the rock within these plagioclase porphyroblasts surrounded by the S_2 foliation plane which formed by tschermakite, biotite and kyanite (Figure 7-b).

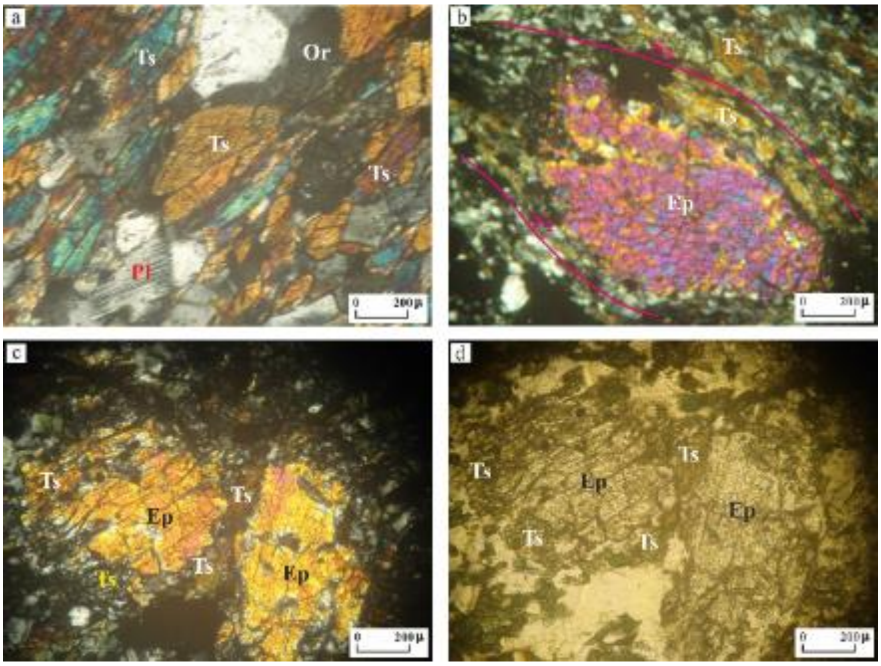

Fig. 6. Hornblende gneiss belonging to the Fındıklı formation (a). The pretectonic epidote porphyroblast according to S_2 foliation (b) and epidote porphyroblast turned to tschermakite (Ts) from the edges (c and d) in the epidote-hornblende gneiss Pl: Plagioclase, Or: Orthoclas. a, b and c: // Nicol, d: / Nicol

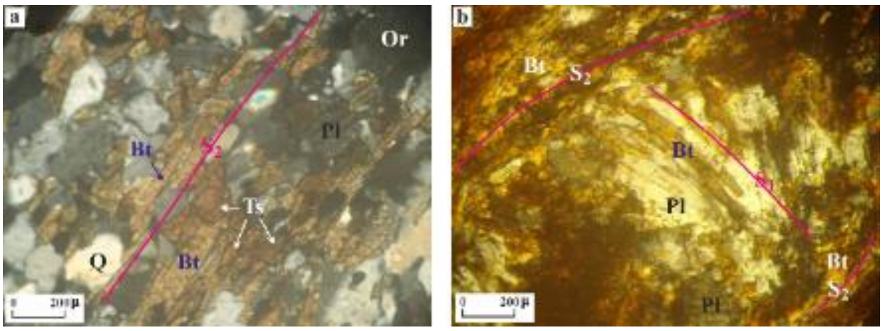

Fig. 7. Biotite-hornblende gneiss (a) and garnet-biotite gneiss (b) belonging to Fındıklı formation. Ts: Tschermakite, Bt: Biotite, Pl: Plagioclase, Or: Orthoclas, Q: Quartz, // Nicol

Therefore, these plagioclases crystallized pretectonically according to the F_2 deformation stage. That these plagioclases occasionally interrupt S_2 foliation (F_2 deformation phase) show that growth of these plagioclases continue after F_2 deformation phase. According to the extinction angle determination, plagioclases are in the composition of albite ($Ab_{94}An_{06}$, $Ab_{93}An_{07}$), oligoclase ($Ab_{77}An_{23}$, $Ab_{72}An_{28}$) and andezine ($Ab_{65}An_{35}$, $Ab_{61}An_{39}$). Plagioclases have been converted to sericite by regressive metamorphism. ***Orthoclases*** are subidioblastic-xenoblastic and generally karlsbad twinning and contain abundant inclusions (Figures 6-a, 7-a and 8). The orthoclases have turned to sericite by retrogressive metamorphism.

Garnet; Amphibole gneisses and biotite gneisses contain garnet crystals formed in two different phases.

The first stage garnets are colorless - pale brownish yellow colored and generally xenoblastic-sometimes sub-idioblastic hexagonal-octagonal prismatic crystals. These garnets, which are observed as very large porphyroblasts, have abundant inclusions. These first stage garnets were surrounded by S_2 foliation that biotite + tschermakite +kyanite form in epidote-biotite gneiss and garnet-biotite gneiss. Therefore, these are pretectonic according to the F_2 deformation stage.

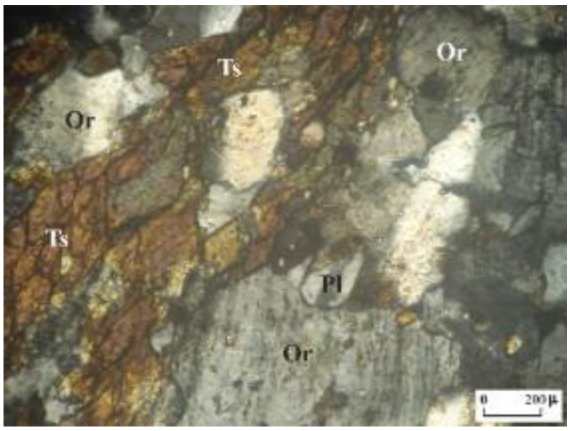

Fig. 8. Tschermakite (Ts), plagioclase (Pl) and orthoclase (Or) observed biotite-hornblende gneiss belonging to Fındıklı formation, // Nicol

The quartz, edenite, staurolite, epidote, zoisite and brown biotite inclusions which form S_1 foliation in the garnet porphyroblasts form the helicytic texture (Figure 9-a). The helicitic texture shows that these garnets are post-tectonic, so that crystallization continue after the F_1 deformation phase. That these garnets interrupt the S_2 foliation (F_2 deformation phase) and are idiomorphic indicates that their growth continues after the F_2 deformation phase (Figure 9-a). The presence of staurolite, edenite and zoisite inclusions in the first stage garnets indicates high pressure areas of the amphibolite facies. These garnets turned to chlorite (ripidolite) from their edges by the retrogressive metamorphism in the greenschist facies, which was the last stage metamorphism in the Kazdağ Massif.

The second stage garnets in amphibole gneisses and biotite gneisses are colorless-pale yellow in color and are generally hexagonal-octagonal idiomorphic, sometimes subidiomorphic crystals. These garnets are generally porphyroblasts and sometimes smaller crystals. These garnets are surrounded by S_2 foliation which brown biotite, tschermakite, long prismatic kyanite and sillimanite form. Therefore, their formation started before the F_2 deformation phase. Especially in biotite-hornblende gneisses, they is syntectonic crystallized according to the S_2 foliation plane (Figure 9-b). They also grew by cutting S_2 foliation in these rocks (Figure 9-c). Hexagonal-octagonal shapes have been sometimes preserved in such garnets. Therefore, second stage garnets in amphibole gneisses and biotite gneisses began to crystallize before the F_2 deformation phase and continued to grow after that phase.

As a result, in amphibole gneisses and biotite gneisses, the first stage garnets should be the product of the first stage metamorphism occurring in conditions ranging from epidote-amphibolite facies to amphibolite facies, where pressure is low and temperature is high temperature. Second stage garnets should be exposed under conditions of upper amphibolite facies with high temperature developed with decreasing pressure and increasing temperature in the environment [21].

Garnets observed in metapelitic schists are colorless - pale yellowish - pale brownish in color and porphyroblast. They are generally subidioblastic-idioblastic hexagonal-octagonal prismatic crystals (Figure 10). Epidote, zoisite / clinozoisite and rutile inclusions are observed in these garnet porphyroblasts (Figure 10-b). Garnets in metapelitic rocks are surrounded by S_2 foliation that brown biotite, muscovite, fibrous sillimanite and long prismatic kyanite form (Figure 10). Therefore, they crystallized pretecttonically according to the F_2 deformation stage. The quartz, epidote, zoisite / clinozoisite and rutile inclusions forming the S_1 foliation in these garnet porphyroblasts form the helicitic texture. Helicitic texture shows that these garnets are post-tectonic according to the F_1 deformation phase (Figure 10-b). That these garnets interrupt S_2 foliation (F_2 deformation phase) and are idioblastic indicates that their growth continues after F_2 deformation phase (Figure 10). Rutile and zoisite inclusions in garnets indicate high pressure areas. These were probably formed under the conditions of amphibolite facies in the high pressure areas of the middle temperature metamorphism, which is the first stage metamorphism.

The garnets turn to partly chlorite (ripidolite) from the edges by the retrogressive metomorphism developed in the last stage and greenschist facies.

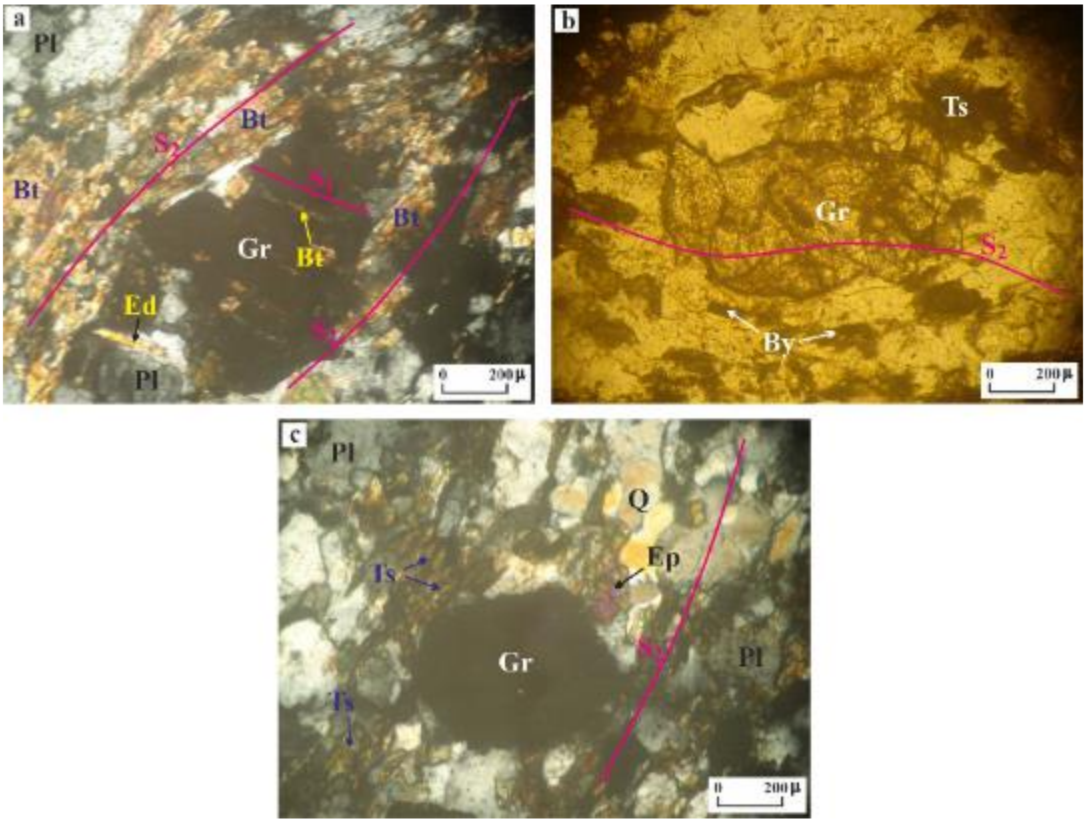

Fig. 9. Garnet-biotite gneiss (a) and biotite-hornblende gneiss (b and c) belonging to Fındıklı formation. Gr: Garnet, Bt: Biotite, Ed: Edenite, Ts: Tschermakite, Pl: Plagioclase, Ep: Epidote and Q: Quartz, a and c) // Nicol, b) / Nicol

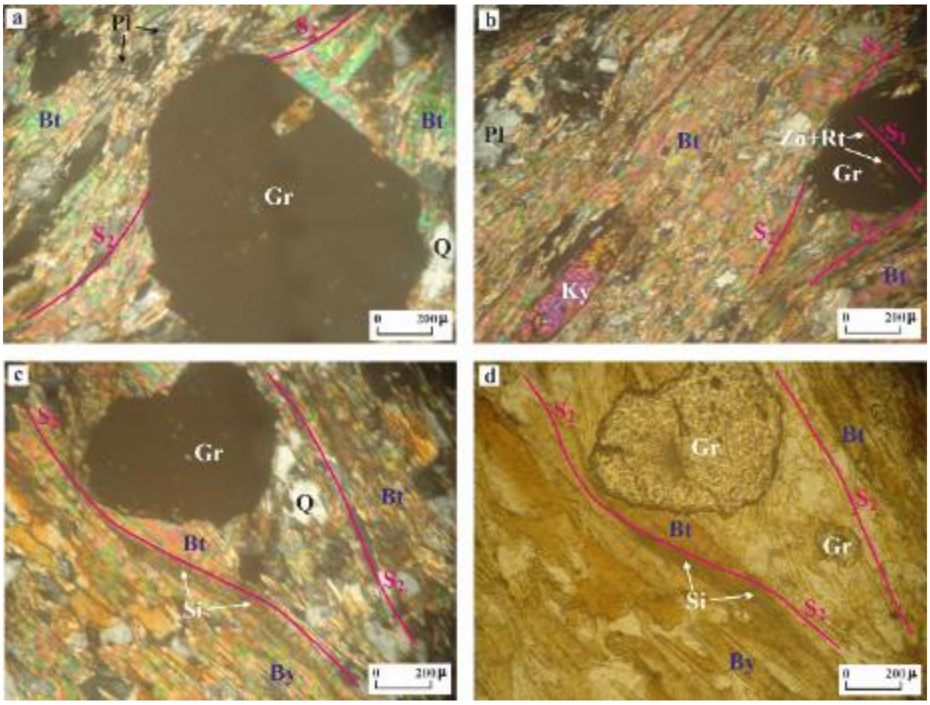

Fig. 10. a) Pretectonic and posttectonic garnet (Gr) porphyroblast according to S_2 foliation observed in kyanite-garnet-mica schist, b) garnet porphyroblast, which show helisitic texture, which is pretectonic and post tectonic according to S_2 foliation and which grow post tectonic according to F_1 deformation stage in kyanite-garnet-biotite schist, c and d) idiomorphic garnet porphyroblasts which grow pretectonic and post tectonic according to S_2 foliation and fibrous sillimanites (Si) transformed from biotite (Bt) observed in kyanite-garnet-mica schist belonging to Fındıklı formation. Ky: Kyanite, Pl: Plagioclase, Q: Quartz, a, b and c: // Nicol, d: / Nicol

Staurolite; was observed approximately 4% in garnet-biotite gneiss. Staurolites are characterized by yellow color, flat extinction, sometimes including quartz inclusions, and subidioblastic-xenoblastic prismatic cyrstals (Figure 11). It is sometimes observed as porphyroblast. Staurolite porphyroblasts are surrounded by S_2 foliation and pretectonic according to F_2 deformation stage. These were probably formed under the conditions of amphibolite facies in the high pressure areas of the middle temperature metamorphism, which is the first stage metamorphism [21]. Particularly in garnet-biotite gneisses, that staurolite is observed parallel to the plaquely biotite and long prismatic tschermakite which form S_2 foliation indicate that they also developed in the F_2 deformation phase (Figure 11).

The presence of staurolite together with kyanite in garnet-biotite gneisses and the presence of sillimanite also in this environment indicate that the staurolites are preserved in the second stage of metamorphism which developed under the conditions of upper amphibolite facies depending decreasing pressure - increasing temperature (progressive metamorphism) in environment. In the garnet porphyroblasts formed during the second metamorphism phase, staurolite inclusions are sometimes observed. Thus, staurolite was transformed into garnet and/or kyanite with progressive reactions (increasing temperature). As a result, staurolites were formed at amphibolite facies in the high pressure areas of the middle temperature metamorphism, which was observed as the first metamorphism in the Kazdağ Massif, and were transformed into garnet and/or kyanite under high amphibolite facies conditions with high temperature with temperature rise.

Kyanite; is generally subidiomorphic and prismatic crystals. It shows the low angled oblique extinction (4^o - 8^o), high relief and bi-directional cleavages perpendicular to each other (Figure 12).

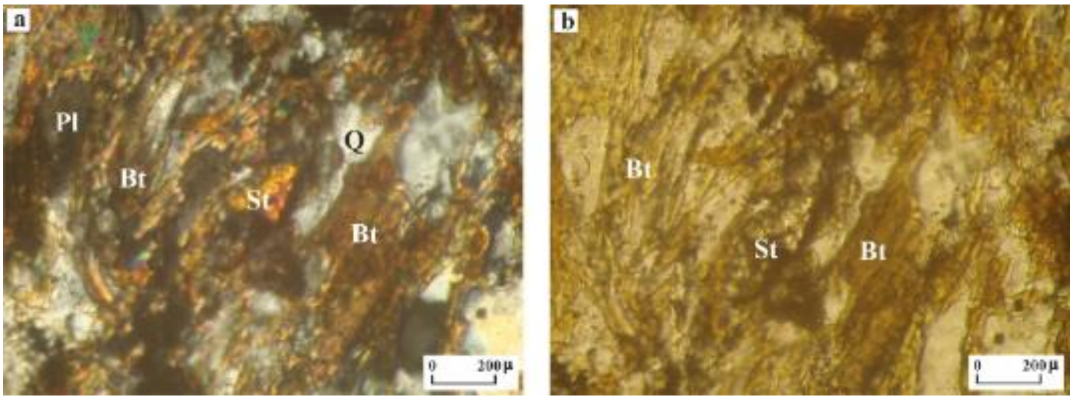

Fig. 11. Staurolite (St), biotite (Bt), plagioclase (P1) and quartz (Q) observed in garnet-biotite gneiss belonging to Fındıklı formation, a: // Nicol, b: / Nicol

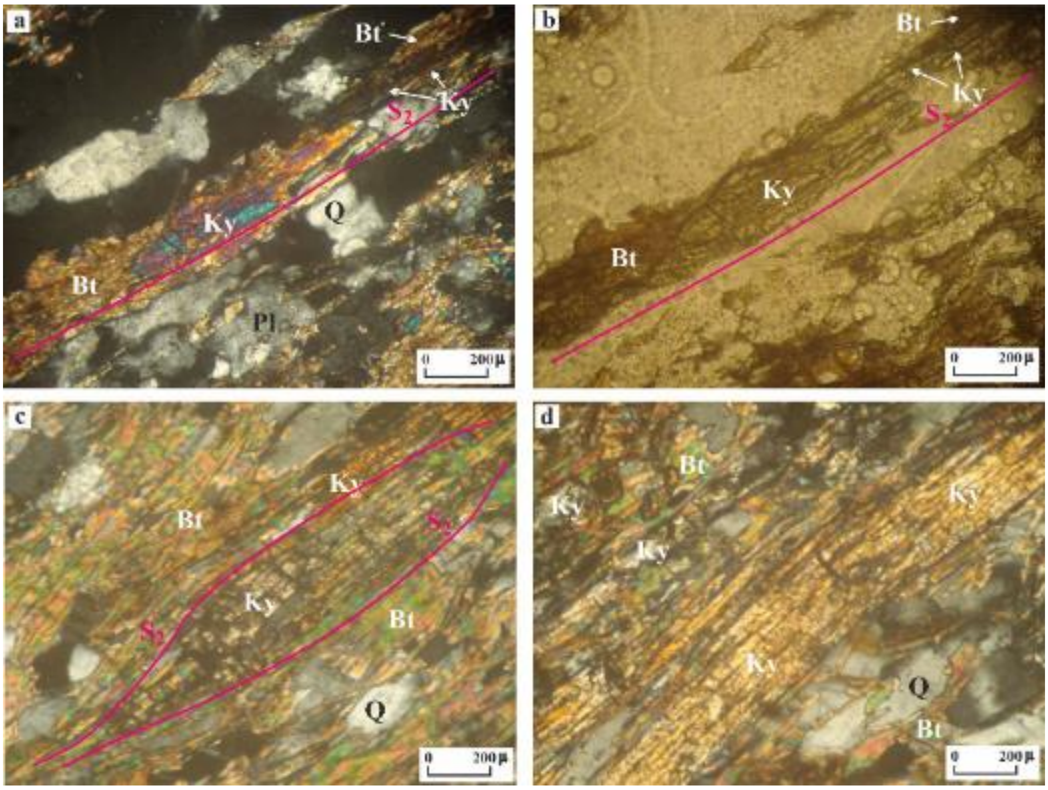

Fig. 12. a and b) Biotite (Bt) and kyanite (Ky) forming S_2 foliation in garnet-biotite gneiss. c) Kyanite (Ky) porphyroblast which developed pretectonic and posttectonic according to S_2 foliation observed in kyanite-garnet-mica schist. d) kyanite(Ky) porphyroblast which developed in the direction of S_2 foliation in kyanite-garnet-biotite schist. Q: Quartz. a, c and d: // Nicol, b: / Nicol

Kyanites observed in biotite-hornblende gneiss, epidote-biotite gneiss, garnet-biotite gneiss and metapelitic schist are sometimes porphyroblast. These porphyroblasts were surrounded by S_2 foliation which show the upper amphibolite facies conditions [21] (Figure 12-c). Therefore, the kyanites are pretectonic according to the F_2 deformation stage. On the other hand, they are in the form of long prismatic crystals aligned parallel to the plaquely biotite and prismatic tschermakites that form the S_2 foliation in the gneisses, and to the elongated-plaquely biotite and muscovites in the metapelitic schists (Figure 10-b, Figures 12-a, b and d). Also sometimes, they interrupt to this foliation partially (Figure 12-c). This shows that the kyanite are also syntectonic and partly postectonic according to the F_2 deformation phase. Therefore, the formation of kyanites began before the F_2 deformation phase and continued its formation in this phase. Kyanites have been formed with progressive metamorphism from especially biotite, sometimes muscovite and possibly staurolite after the amphibolite facies conditions in the high pressure areas of the middle temperature metamorphism which is the first stage metamorphism [21] in amphibole gneisses, biotite gneisses and metapelitic schists in the Kazdağ Massif. Some kyanite porphyroblasts have been transformed into fibrous sillimanites from their crystal edges in amphibole and biotite gneisses. This indicates a progressive metamorphism (increasing temperature) in environment. The presence of kyanite and sillimanite together in biotite-hornblende gneisses and metapelitic schists indicates that the kyanite is still preserved under the conditions of the second stage metamorphism in the upper amphibolite facies.

Sillimanite; is in the form of fibrous-shaped and flat extinguished crystals (Figures 10-d and 13). The sillimanite crystals observed in the gneisses and metapelitic schists were formed with the progressive reactions from especially biotite and sometimes kyanite and muscovite in the second metamorphism conditions developed in the upper amphibolite facies after the first stage metamorphism developed in the amphibolite facies in the high pressure areas of the middle temperature metamorphism [21] (Figures 10-d and 13). The fibrous sillimanite crystals are aligned parallel to the S_2 foliation which are composed of biotites and tschermakites in amphibole and biotite gneisses and which are composed of brown colored biotites and muscovites in metapelitic schists (Figure 13). Sillimanites are observed together with orthoclase in gneisses and metapelitic schists.

Epidote group; is observed as epidote and zoisite / clinozoist in amphibole gneisses and biotite gneisses. These minerals are typical of very high relieves and prismatic shapes Epidote are characterized with medium double refractions, and zoisite / clinozoisites are characterized with abnormal blue double refractions. Epidote and zoisite / clinozoicides are generally observed as porphyroblasts.

In particular, the epidote porphyroblasts were surrounded by S_2 foliation formed by tschermakites in the epidote-hornblende gneisses (Figure 6-b). Epidote and zoisite / clinozoisite porphyroblasts were surrounded by S_2 foliation formed by biotite + kyanite in epidote-biotite gneisses. Therefore, these epidote and zoisite / clinozoisite porphyroblasts are pretectonic according to F_2 deformation stage. In amphibole gneisses, brown biotite, edenite, chlorite, barroisite and epidote inclusions extending in one direction in the plagioclase porphyroblasts form the S_1 foliation plane of the rock. The quartz, edenite, staurolite, epidote, zoisite and brown colored biotite inclusions which form S_1 foliation in the first stage garnet porphyroblasts surrounded by the S_2 foliation which biotite+tschermakite+kyanite form in the epidote-biotite gneisses and garnet-biotite gneisses form helicitic texture.

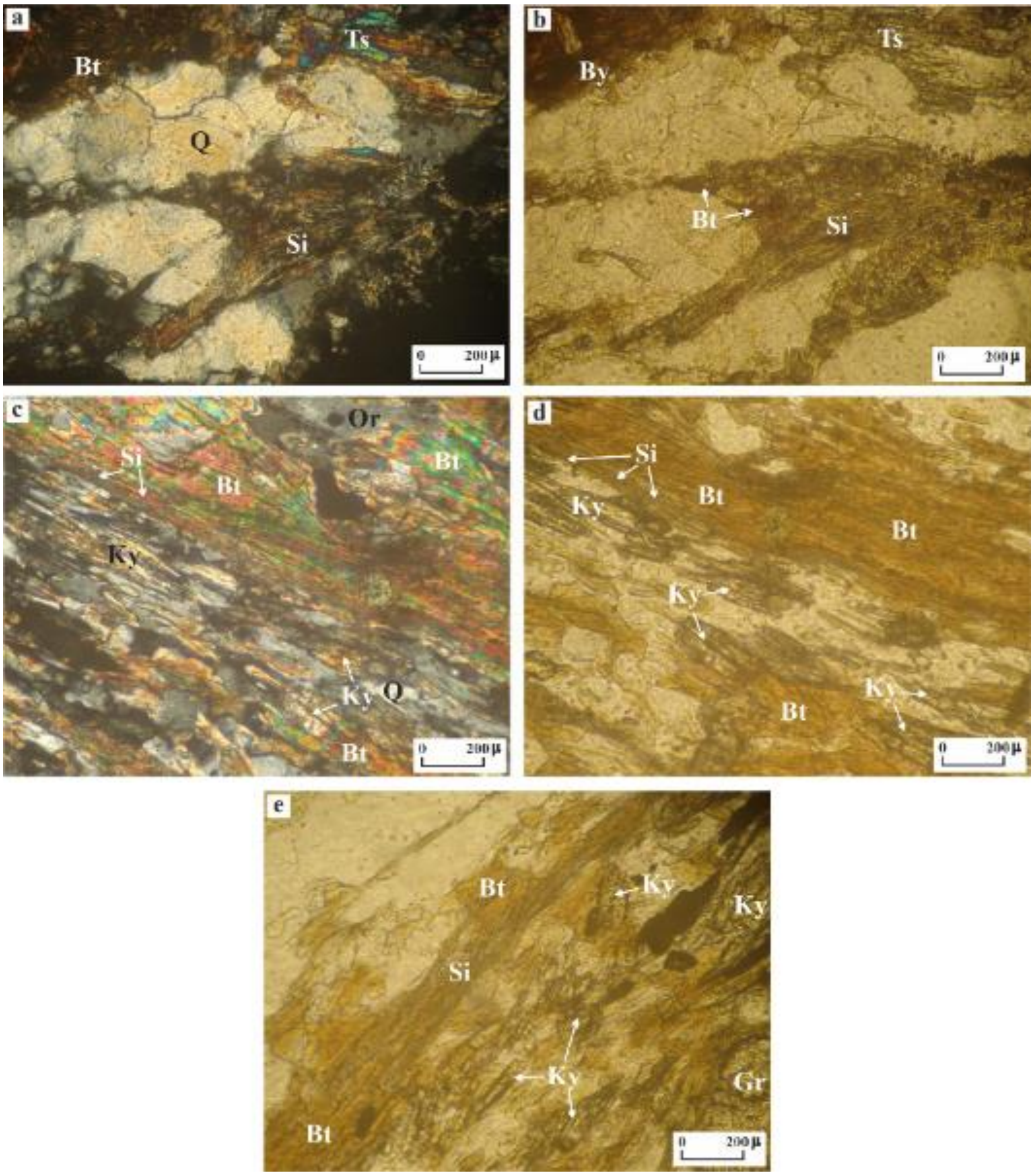

Fig. 13. The fibrous sillimanite (Si) crystals transformed from the biotite observed garnet-biotite gneisses (a and b) and in kyanite-garnet-mica schists (c, d and e) belonging to the Fındıklı formation. Bt: Biotite, Ky: kyanite, Gr: Garnet and Q: Quartz, a and c: // Nicol, b, d and e: / Nicol

All these features show that epidotes and zoisites are formed under amphibolite facies conditions in high pressure areas of middle temperature metamorphism which are the first stage metamorphism. The presence together with barroisite and chlorite of epidotes which form S_1 foliation in the plagioclase porphyroblasts and the presence of plagioclases at albite composition in these rocks indicate that the beginning of the metamorphism in this amphibolite facies occurs in the epidote-amphibolite facies.

In particular, epidote porphyroblasts surrounded by S_2 foliation in epidote-hornblende gneisses have been transformed into edenite and tschermakite by progressive reactions from the edges (Figures 6-c and d). The epidote → edenite transformation shows that the first stage metamorphism in the amphibolite facies develops in the form of progressive reactions (increasing temperature) from the epidote-amphibolite facies to the amphibolite facies. Epidote → tschermakite transformation shows upper amphibolite facies conditions at high temperature observed as second stage metamorphism in the Kazdağı Massif with temperature increase.

The minerals and their percentage values identified in nine samples belonging to amphibole gneisses biotite gneisses and metapelitic schists are given in Table 1.

Thickness and contact relations

Amphibole gneisses, biotite gneisses, biotite schists and mica schists, which form the dominant lithology of the Fındıklı formation, are generally alternation with crystallized limestones of Altınoluk marble member (Figures 3 and 14-a). In the study area, the bottom boundary of the Fındıklı formation cannot be observed, and this formation is covered by a tectonic contact by the Tozlu formation from the top (Figure 14-b). Therefore, the stratigraphic thicknesses of the gneisses and metapelitic schists, which form the dominant lithology of the Fındıklı formation, are variable. Fındıklı formation shows a visible thickness of approximately 1600 m in the southwest of the study area where the thickest outcrops take place.

Table 1. Components, % values of the components and rock names of nine samples belonging to amphibole gneisses, biotite gneisses and metapelitic schists observed in Fındıklı formation

The Name of Mineral	**The Name of Rock**								
	Hornblende gneiss	**Biotite-hornblende gneiss**	**Epidote-hornblende gneiss**	**Garnet-hornblende gneiss**	**Epidote-biotite gneiss**	**Garnet-biotite gneiss**	**Kyanite-garnet-mica schist**	**Kyanite-garnet-biotite schist**	**Kyanite-garnet-biotite schist**
Quartz	26	19	20	25	19	18	8	10	7
Plagioclase	15	13	16	18	14	12	3	3	4
Orthoclase	22	6	-	6	2	4	4	2	4
Muscovite	-	2	-	-	-	-	3	2	-
Biotite	3	12	2	3	25	25	44	53	45
Hornblende	25	20	21	25	3	5	-	-	-
Garnet	-	8	-	13	4	12	12	14	15
Kyanite	-	6	-	2	7	5	10	7	8
Staurolite	-	-	-	-	-	4	-	-	-
Sillimanite	-	5	-	-	-	3	9	2	7
Epidote	3	2	17	2	10	1	1	1	2
Zoisite / Clinozoisite	1	1	11	1	3	-	1	-	1
Chlorite	3	2	7	2	6	6	2	4	3
Calcite	-	-	3	-	3	2	-	-	-
Microcline	-	2	2	-	1	-	-	-	-
Tourmaline	-	-	-	1	1	1	1	-	1
Rutile	-	-	-	1	-	1	1	-	1
Apatite	1	1	-	-	1	1	1	1	1
Sphene	1	1	1	1	1	-	-	1	1
TOTAL	100	100	100	100	100	100	100	100	100

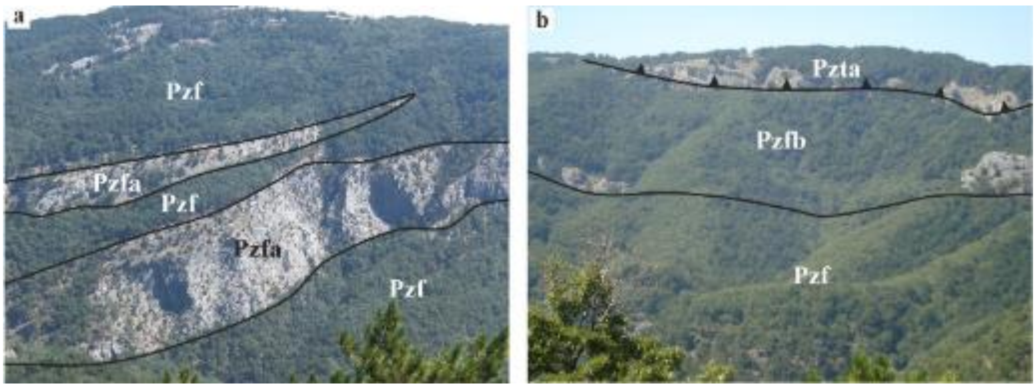

Fig. 14. a) Amphibole-biotite gneisses and metapelitic schists (Pzf) belonging to the Fındıklı formation, and the Altınoluk marble member (Pzfa), which consists of crystallized limestones belonging to the Fındıklı formation, which shows alternation with these gneisses and schists observed at Naldırbasan Ridge (the photo was taken by looking at east). b) Amphibole-biotite gneisses and metapelitic schists (Pzf) belonging to the Fındıklı formation at the bottom, higher up crystallized limestones belonging to Babadağ marble member (Pzfb) of the Fındıklı formation, and amphibolite member (Pzta) according to Tozlu formation observed with a tectonic contact at the top, which are observed on Yüksek Hill and its eastern slopes (the photo was taken by looking at west)

In the study area, the base of the Fındıklı formation, which forms the core of the Kazdağ Massif, could not be observed. The gneisses and metapelitic schists of the Fındıklı formation (Figure 14-a) are overlain as concordant stratigraphically by the Babadağ marble member of the Fındıklı formation (Figures 3 and 14-b). In the southwest and southern parts of the study area, these gneisses and metapelitic schists are tectonically overlain by Tozlu formation in places where the Babadağ marble member disappeared and by Sütüven formation in places where Tozlu formation disappeared (Figure 2).

A.1. Altınoluk marble member

Definition and spread

The unit is composed of crystallized limestones (Figure 15). It was named as Altınoluk marble member within the Fındıklı formation by [17]. The unit which show alternation with amphibole-biotite gneisses and metapelitic schists of Fındıklı formation is observed in Tellitoprak Hill, Zeybektaşı Hill, Gemiburnu Hill, Naldırbasan Ridge, east and south slopes of Kazanoluk Hill, east of Ardıçlı Hill, Dirsektaş Hill, Zığın Hill and vicinities of Öküzçukuru Ubiety (Figure 2).

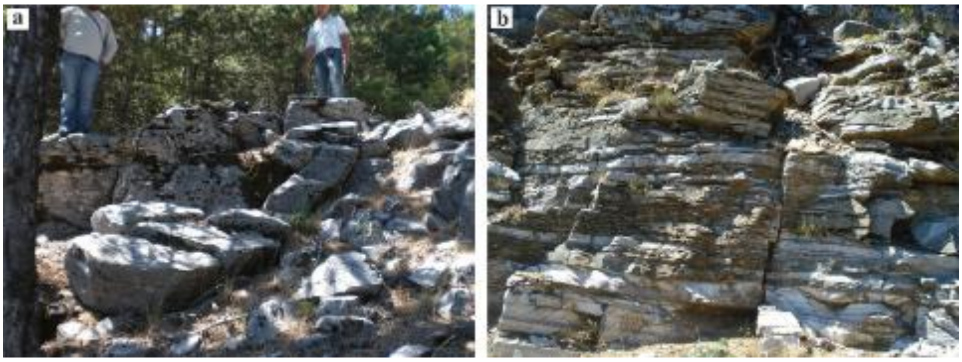

Fig. 15. a) Crystallized limestones belonging to Altınoluk marble member observed north of Mandıra Hill. b) Alternation of crystallized limestone (light colored levels) - gneiss (dark colored levels) in Altınoluk marble member observed northeast of Dirsektaş Hill

Lithology and petrography

Altınoluk marble member is composed of gray-light pink colored and thin-medium bedded crystallized limestones (Figure 15-a). Crystallized limestones are very hard, medium-coarse crystalline and sugar textured. There are abundant secondary calcite veins scattered in different directions within the crystallized limestones. The crystallized limestones pass gneisses by alternating with the gneisses in case of thin levels at their upper sections (Figure 15-b). The curved structures are observed quite frequently in the unit.

Fabric and mineralogy

Calcite ± muscovite ± quartz ± apatite mineral paragenesis is observed in crystallized limestones. These rocks show granoblastic texture. The calcites, which make up more than 95% of the crystallized limestones, are xenoblastic and show partly bidirectional cleavage and medium-coarse crystals.

Thickness and contact relations

The crystallized limestones belonging to the Altınoluk marble member of the Fındıklı formation show alternation with amphibole-biotite gneisses and metapelitic schists. Especially in the SSW part of Kaz Mountain, These metacarbonates are observed in the form of numerous bands generally in thicknesses ranging from 10 m to 120 m between amphibole-biotite gneisses and metapelitic schists. Therefore, lateral changes in thickness of crystallized limestones are observed. They usually disappears by wedging within the gneisses (Figure 14-a). They presents an apparent thickness of approximately 300 m at vicinity Öküzçukuru Ubiety where the thickest outcrops of metacarbonates take place.

A.2. Babadağ marble member

Definition and spread

It is made of crystallized limestones. It was named according to their outcrops which are observed typically around Babadağ Hill by [17]. In the study area, it is observed at west of Babadağı Hill, Yelpez Hill, Kalabak Hill, Kavakkıranı Hill, northeast of Isırganlı Hill and in the vicinities of Yüksek Hill (Figure 2).

Lithology and petrography

The Babadağ marble member belonging to the Fındıklı formation is composed of gray-white colored, coarse crystalline and thin-medium bedded crystallized limestones (Figure 16). They are characterized by massive appearances at their hand samples. They presents a weak foliation structure at the levels where phyllosilicate minerals increased. In the crystallized limestones, which are mostly observed as coarse crystalline grains, abundant fractured structures are dominant. The cracks are mostly filled with secondary calcite minerals. As a result of the intense metamorphism and deformation observed in the Kazdağ Massif, overturned and horizontal isoclinal folds and Z-folds developed in these metacarbonates.

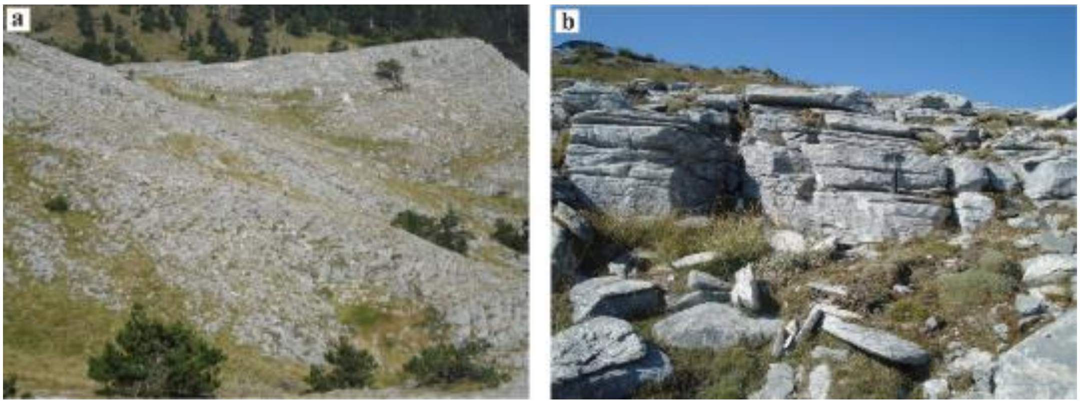

Fig. 16. The crystallized limestones belonging to the Babadağ marble member observed to the south of Çıplak Hill

Fabric and mineralogy

Calcite ±quartz ± apatite mineral paragenesis occurs in the crystallized limestones belonging to the Babadağ marble member. These metacarbonates, which consist of almost completely round or close to round xenoblastic and big calcite crystals (98%), are composed of coarse calcite crystals show granoblastic texture (Figure 17).

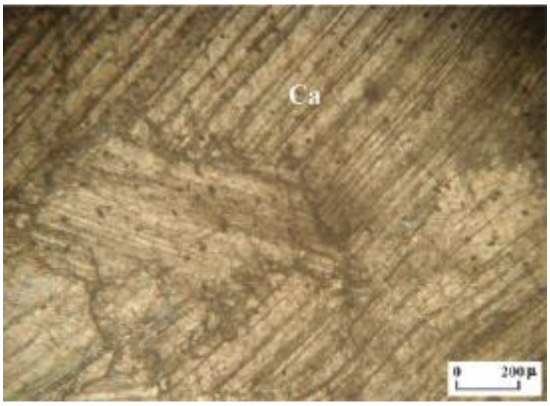

Fig. 17. Crystallized limestone of Babadağ marble member. Ca: Calcite, // Nicol

Thickness and contact relations

The Babadağ marble member belonging to the Fındıklı formation has a visible thickness of approximately 500 m. It forms the top level of the Fındıklı formation in the study area. The Babadağ marble member is transitionally compatible with the amphibole-biotite gneisses and metapelitic schists of the Fındıklı formation from below (Figure 3). Sometimes lateral-vertical transitions are observed at these borders. From the top, it is covered by a tectonic contact by the Tozlu formation (Figures 2, 3 and 18).

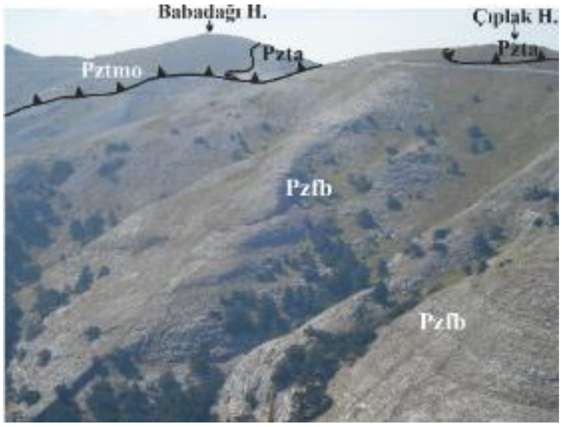

Fig. 18. The appearance of Babadağ marble member (Pzfb) belonging to Fındıklı formation (Pzmo) and Amphibolite member (Pzta) and Metaophiolite member (Pztmo) belonging Tozlu formation observed at Babadağı Hill and Çıplak Hill and their southeast and south slopes (the photo was taken by looking at northwest)

B. Tozlu Formation

The unit is composed of amphibolite, metadunite, metaproxenite, metaproxenhornblendite, serpentinite and small amount of crystallized limestones with lateral to vertical transition with each other. The unit is named Tozlu formation by [12]. Amphibolites and metaophiolites are intrpenetrate with each other. Amphibolites are commonly observed in the upper and lower levels of the formation, and metaophiolites are commonly observed in the middle levels (Figure 3). Crystallized limestones are in fine levels within the formation. Tozlu formation is located on the Fındıklı formation with a tectonic contact. Tozlu formation is unconformably overlain by Sarıkız formation from the top (Figures 2 and 3).

B.1. Amphibolite member

Definition and spread

It is mainly composed of amphibolites and amphibole schists. The unit was identified and mapped as “amphibolite” in the Tozlu formation by [24]. In this study, these amphibolites were distinguished as “amphibolite members” in the Tozlu formation., The member is observed at Güventaş Rocks, Tavşanoynağı Hill, Isırganlı Hill, Kaz Mountain, Tozluyayla Ridge, southern parts Ortaca Hill and Çatalgedik Hill and the vicinities of Çıplak Hill and Aktaş Hill in the study area (Figure 2).

Lithology and petrography

The unit is composed of dark grayblack colored, generally massive - sometimes foliated amphibolites and amphibol schists (Figure 19-a). Metadunite and metaproxenite interlevels belonging to metaophiolite member are observed within the unit. The banded, ribboned and leopar patterned structures are observed depending on the sequence of hornblende and plagioclase crystals in amphibolites which exhibit medium - coarse grained structures (Figure 19-b). Prismatic shaped and black colored hornblendes and grayish white colored and subidioblastic plagioclases are very prominent in the unit. Amphibolites, generally presenting massive structures, sometimes have had schistosity with elengation in one direction of long prismatic hornblende crystals, and thus they have passed to amphibol schists. Schistosity structured amphibol schists are commonly observed in the bottom levels of the Tozlu formation. Isoclinal folds are frequently observed in amphibolites with fractured structures.

Fabric and mineralogy

Hornblende (tschermakite and edenite) + plagioclase (albite-oligoclas-andesine) + chlorite (ripidolite-picnochlorite, clinochlorine) ± garnet ± orthoclase ± epidote ± zoisite / clinozoisite ± quartz ± sphen ± apatite ± rutile minerals are observed in amphibolite and amphibol schists belonging to amphibolite member of the Tozlu formation (Figure 20). These metabasic rocks are porphyroblastic and nematoblastic in texture.

Amphibole; consists of commonly tschermakite (Figure 20) and a small amount of edenite. ***Edenites*** are prismatic shaped, green-dark green colored and show low angled oblique extinction between 18° - 23°. They are observed as porphyroblasts in some amphibolite samples. These edenite porphyroblasts have been transformed into brownish green colored tschermakites from their edges. This indicates an increase temperature in environment after amphibolite facies metamorphism which has high pressure, which initially developed in the Kazdağ Massif.

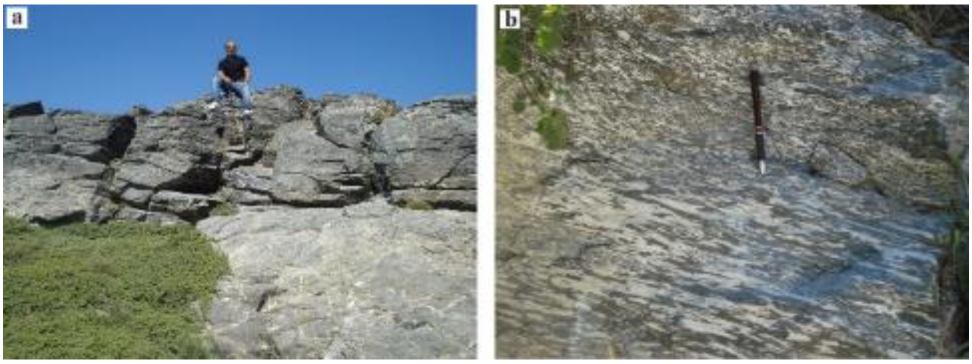

Fig. 19. Amphibolites belonging to Tozlu formation observed at west of Tozluyayla Ridge, b) Banded structure and leopard patterned amphibolites observed at Tozluyayla Ridge

Tschermakites, which the main component of the amphibolites form and which are commonly observed, are typically with prismatic shapes and brownish green colors. They show an oblique extinction between 17^o-21^o. They are sometimes observed as porphyroblasts in amphibolites. Epidote, quartz, plagioclase, zoisite and opaque mineral inclusions are observed in these porphyroblasts. Tschermakites observed in some amphibol schists are in the form of long prismatic crystals arranged parallel to S_2 foliation. Therefore, these tschermakites should be exposed under the conditions of upper amphibolite facies at high temperature which is the second stage metamorphism and is observed in Kazdağ Massif together with temperature increase. Tschermakites have been transformed into chlorite from the crystal edges by retrogressive reactions as a result of the last metamorphism observed in the Kazdağ Massif.

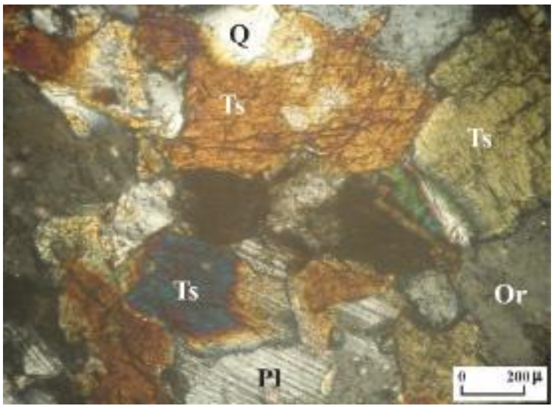

Fig. 20. Tschermakite (Ts), plagioclase (P1), orthoclase (Or) and quartz (Q) observed amphibolite belonging to amphibolite member, // Nicol

Feldspars*;** are observed as plagioclase and orthoclase. ***Plagioclases are in case of subidiyoblastic-prismatic crystals. Sometimes they contains inclusions. They is sometimes observed as porphyroblast in metabasites. According to extinction angle determination in twin plagioclases, plagioclases are in albite ($Ab_{93}An_{07}$), oligoclas ($Ab_{78}An_{22}$, $Ab_{80}An_{20}$) and andesine ($Ab_{67}An_{33}$, $Ab_{62}An_{38}$) compositions. ***Orthoclases*** are observed in small amounts in metabasites. Orthoclases are generally in the form of xenoblastic crystals. Karlsbad twins and abundant inclusions are evident in these. Orthoclases and plagioclases within amphibolites turned to sericite with retrogressive metamorphism.

***Chlorite*;** is observed up to 10% in amphibolites. Some of the chlorites are pale green colored, flaky-plaquely shaped and possibly are in Mg-chlorite (clinochlorine) composition. Another chlorite observed in the metabasites is green colored Mg-Fe chlorites (ripidolite-picnochlorite) which formed by retrogressive reactions from garnets and hornblendes. They are characterized by abnormal brown birefringence colors and flaky-plaquely shapes.

The minerals and their percentage values identified in three samples belonging to amphibolite and amphibol schists are shown in Table 2.

Table 2. The components,% values of components and rock names of three samples belonging to amphibolite and amphibole schists

	The Name of Rock		
The Name of Mineral	**Amphibolite**	**Amphibole schist**	**Amphibole schist**
Tschermakite	54	51	69
Edenite	3	2	-
Plagioclase	22	25	16
Chlorite	6	10	5
Epidote	2	3	2
Zoisite/ Clinozoisite	1	1	2
Orthoclase	3	2	-
Quarts	5	4	4
Garnet	2	-	-
Rutile	1	-	-
Sphene	1	1	1
Apatite	-	1	1
TOTAL	100	100	100

Thickness and contact relations

Amphibolites and metaophiolites belonging to the Tozlu formation are interpenetrant with each other. Amphibolites are commonly observed in bottom and upper levels of the formation, and metaophiolites are commonly observed in the middle levels. The amphibolite member commonly observed at the bottom of the Tozlu formation is stratigraphically located on Babadağ marble member belonging to Fındıklı formation with a tectonic contact (Figures 2, 14-b and 18)., Amphibolite member overlies tectonically amphibole-biotite gneisses and metapelitic schists of the Fındıklı formation in places where Babadağ marble member disappears (Figures 2 and 21). The amphibolite member of the Tozlu formation is unconformably covered by the Sarıkız formation in most of the study area. It is covered by tectonic contact by Sütüven formation at around Aktaş Hill in the southwest of the study area (Figure 2). The detectable apparent thickness of amphibolite member is estimated to be about 800 m.

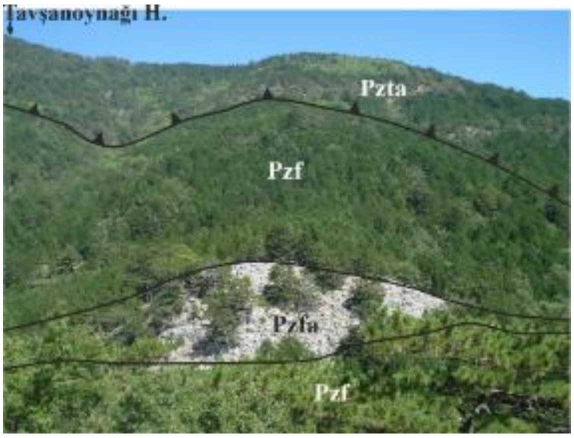

Fig. 21. The view from amphibolite member (Pzta) belonging to Tozlu formation, Fındıklı formation (Pzf) and Altınoluk marble member (Pzfa) belonging to Fındıklı formation observed at Tavşanoynağı Hill and at 1390 m altitude hill and at suthern of Tavşanoynağı Hill and on the western slopes of these hills (the photo was taken by looking at ENE direction)

B.2. Metaophiolite member

Definition and spread

It is mainly composed of metadunite, metaproxenite, metaproxenhornblendite and serpentinite. The unit was identified and mapped as "metadunite" in the Tozlu formation by [24]. Since the unit is of metaophiolite character and is composed of metaperidodite, metaproxenite and metahornblendite, it has been named as "metaophiolite membe" in Tozlu formation in this study. The unit outcrops at arounds of Kızıltaş Ridge, Babadağı Hill, Atçukuru Ridge, Kırklar Hill, Kaz Mountain, Karadikme Hill, Dökük Rocks, Çizme Hill, east of Aktaş Hill and Sarıtaş Hill in the study area (Figure 2).

Lithology and petrography

The unit is composed of metadunite, metaproxenite, metaproxenhornblendite and serpentinite (Figure 22). These rocks belonging to metaophiolite member are characteristic with yellowish-light brownish alteration colors and fresh surface colors of green, greenish black and dark gray. Amphibolite interlevels belonging to amphibolite member are composed within the unit. These metaophiolitic rocks are characterized by medium to coarse grained crystals. Green colored coarse proxene crystals are particularly prominent in metaproxenites, and green-black colored coarse proxene and hornblende crystals are very prominent in metaproxenornblendites. Metadunite, metaproxenite and metaproxenhornblendite show massif and sometimes foliated structure. The serpentinites in the unit are green colored and massive.

Fabric and mineralogy

Metadunites belonging to metaophiolite member include *relict olivine* ± *relict clinoproxene (diopside/augite)* + *serpentine (chrysotile)* + *chlorite (clinochlorine, ripidolite-picnochlorite)* mineral assemblage. *Relict clinoproxene (diopside/augite)* + *chlorite (clinochlorine, ripidolite-picnochlorite)* + *relict orthoproxene (enstatite)* ± *epidote* ± *zoisite / clinozoisite* ± *sphene* ± *apatite* ± *rutile* minerals are observed in **metaproxenites**. **Metaproxenhornblendites** include *relict Mg-hornblende* + *relict clinoproxene (diopside/augite)* + *chlorite (clinochlorine, ripidolite-picnochlorite)* ± *epidote* ± *zoisite / clinozoisite* ± *sphene* ± *apatite* ± *rutile* mineral paragenesis. *Serpentine (antigorite and chrysotile)* + *relict olivine* + *tremolite* ± *chlorite (clinochlorine)* ± *talc* minerals are observed in **serpentinites**. Metadunites, metaproxenites and metaproxenhornblendites show blastogranular texture. Serpentinites are prominent with lepidoblastic (antigorite is predominant) and sieve textures (chrysotile is predominant).

***Olivine*;** is observed as relict cyrstals which are form before metamorphism in metadunites and serpentinites. Olivines are xenoblastic-subidioblastic crystalline and fractured. Olivines in these rocks have been turned to serpentine, Mg-chlorite (clinochlorine) and Mg-Fe chlorite (ripidolite) by metamorphism.

***Clinoproxen (Diopside/Augite)*;** are observed as residual crystals remaining from ultramafic rocks before metamorphism in metadunites, metaproxenites and metaproxenhornblendites. Clinoproxenes have long-short prismatic shape and show bi-directional cleavages and are very pale green color (Figure 23-a). It shows an oblique extinction between 40^{o}-44^{o}. Clinoproxenes are probably in the "diopside/augite" composition with these properties. Clinoproxenes in metaproxenites and metaproxenhornblendites have been turned to Mg-chlorite (clinochlorine) and Mg-Fe chlorite (ripidolite) by metamorphism.

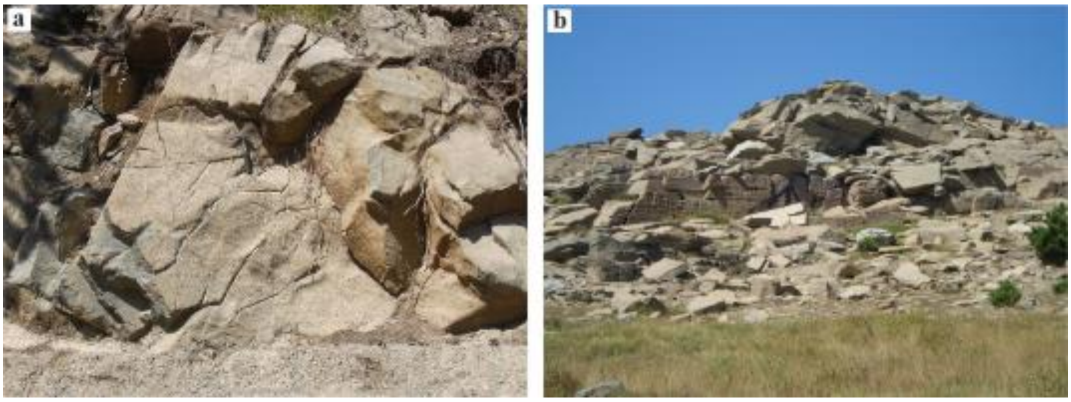

Fig. 22. Metaproxenites (a) observed north of Tozluyayla Ridge and metadunites (b) observed in the northeast of Karataş Ridge belonging to metaophiolite member

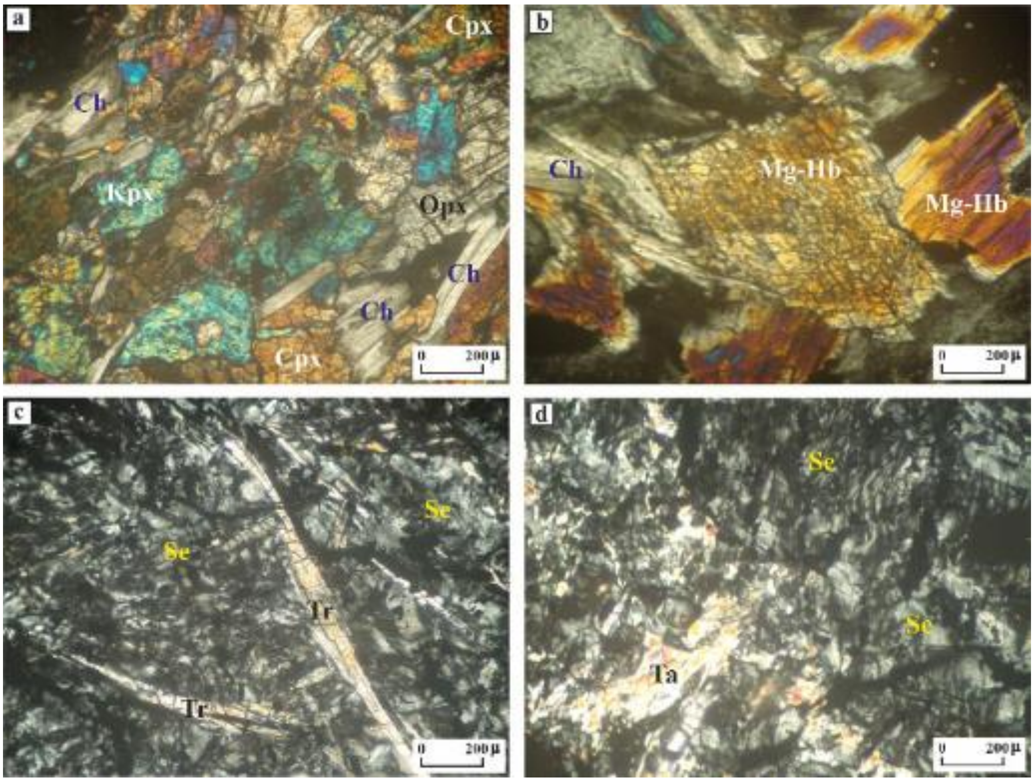

Fig. 23. a) Relict clinoproxene (Cpx), relict orthoproxene (Opx) and chlorite (Ch) in metaproxenite, b) Relict Mg-hornblende (Mg-Hb) and chlorite in metaproxenhornblendite, c and d) Serpentine (Se), tremolite (Tr) and talc (Ta) in serpentinites, // Nicol

Orthoproxene (Enstatite)**;** is observed as residual crystals in metaproxenites. The orthoproxenes are short-long prismatic in shape and markedly bi-directional to each other with a cleavage (Figure 23-a). Orthoproxenes are probably in the composition of enstatite because of they are flat extinction and very pale green - colorless. Orthoproxenes in metaproxenites are sometimes turned to Mg-chlorite (clinochlorine) by metamorphism.

Hornblende (Mg-hornblende)**;** form the main component of metaproxenhornblendites. It is observed as residual crystals remaining from ultramafic rock before metamorphism. Hornblendes are prismatic in shape and pale green - green in color. In short prismatic ones, bi-directional cleavages are evident (Figure 23-b). It shows oblique extinction between about 18^{o}-22^{o}. Therefore, it is thought that hornblendes are in Mg-hornblende composition. Mg-hornblendes observed in metaproxenhornblendites are sometimes turned to Mg-chlorite (clinochlorine) by metamorphism.

Serpentine; form the main component of serpentinites (Figures 23-c and d). It is characterized by very low birefringences and very pale green colors. Serpentines are observed as "antigorite" (leafy shaped) and "chrysotile" (fibrous shaped) in serpentinites. They were formed by the effect of metamorphism from olivines.

Chlorite**;** The pale-very pale green colored and leafy shaped chlorites are Mg-chlorite (clinochlorine) (Figures 23-a and b). They sometimes have brought the foliation to these rocks by extending in one direction in metadunites, metaproxenites and metaproxenhornblendites. The other chlorites observed in meta-ophiolites are Mg-Fe chlorites (ripidolite-picnochlorite), which are green-colored and show leafy form and abnormal brown-blue birefringence colors. Chlorites are formed from olivines in metadunites and from proxenes in metaproxenites and from hornblendes and clinoproxenes in metaproxenhornblendites by metamorphism.

Tremolite**;** is observed as long prismatic crystals in serpentinites (Figure 23-c). It is evident with colorless-very pale green colors and low angled oblique extinctions between 8^{o}-12^{o}.

Talc; is xenoblastic and subidioblastic. The platy shapes are prominent in the subidioblastic ones. Talc observed in serpentinites are typical with its high birefringence color and its low relief (Figure 23-d).

The minerals and their percentage values identified in four samples belonging to metadunite, metaproxenite, metaproxenhornblendite and serpentinite are given in Table 3.

Thickness and contact relations

The stratigraphic position of metaophiolites in Tozlu formation is not clear in the study area. In contrast, it is generally observed at middle levels of Tozlu formation. Metaophiolites are mostly interpenetrant situation with amphibolites of Tozlu formation in the study area (Figure 24-a). Metaophiolite member is located with a tectonic contact on the Babadağ marble member of Fındıklı formation (Figures 2, 18 and 24-a). , it overlies tectonically the amphibole-biotite gneisses and metapelitic schists of the Fındıklı formation in plaes where the Babadağ marble member disappeared. Metaophiolite member is unconformably overlain by Sarıkız formation from the top. It is covered by a tectonic contact by Sütüven formation at the vicinity of Sarıtaş Hill in the northeast of study area and at the south of Düden Hill west of study area (Figure 2). The detectable apparent thickness of meta-ophiolite member is approximately 500 m.

Table 3. The components, % values of the components and rock names of four samples belonging to metadunite, metaproxenite, metaproxenhornblendite and serpentinite

The Name of Mineral	The Name of Rock			
	Metadunite	**Metapyroxenite**	**Metapyroxene-hornblendite**	**Serpentinite**
Olivine (relict)	71	-	-	2
Clinopyroxene (relict)	2	69	8	-
Orthopyroxene (relict)	-	8	-	-
Hornblende (relict)	-	-	64	-
Chlorite	12	18	22	7
Epidote	-	1	2	-
Zoisite/ Clinozoisite	-	1	1	-
Serpentine	5	-	-	83
Tremolite	-	-	-	4
Talc	-	-	-	4
Rutile	-	1	1	-
Sphene	-	1	1	-
Apatite	-	1	1	-
TOTAL	100	100	100	100

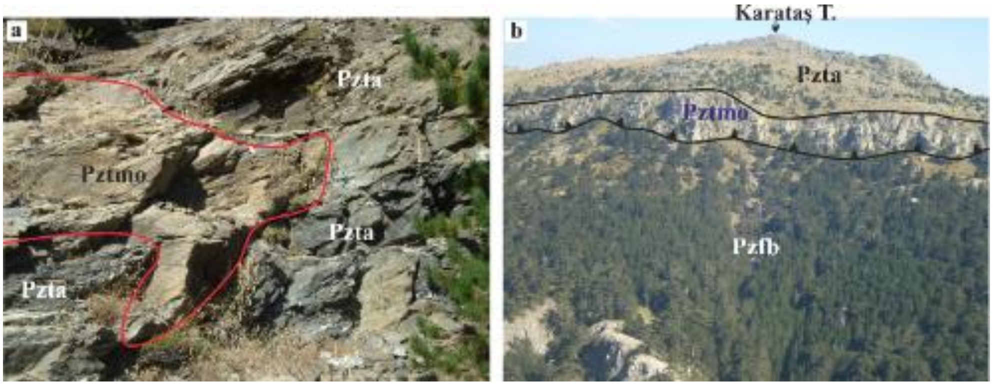

Fig. 24. a) The interpenetrant boundary relationship between the metaophiolite member (Pztmo) and amphibolite member (Pzta) belonging to Tozlu formation observed in south of Dumanlıyayla Ubiety located at west of Tavşanoynağı Hill, b) the metaophiolite member (Pztmo) and amphibolite member (Pzta) belonging to Tozlu formation and Babadağ marble member (Pzfb) belonging to Fındıklı formation (Pzfb) observed on Karataş Hill and its northwest slope (the photo was taken by looking at southeast direction)

B.3. Marble member

Definition and spread

It is made of crystallized limestones. The unit was separated and mapped as “marble” in Tozlu formation by [24]. It has been defined as “marble member” in Tozlu formation in this study. The unit is observed in very narrow levels within the Tozlu formation in the study area. It is observed in very narrow areas at the south of Ortaca Hill and at north and northeast of Karataş Hill in the study area (Figure 2).

Lithology and petrography

The marble member of the Tozlu formation is composed of white - milk white colored and thin - medium bedded crystallized limestones. These metacarbonates are generally medium grained, massive in hand samples and cracked. The cracks are usually filled with secondary carbonate minerals. The unit is evident in case of milky white colored and layered thin levels among amphibolites and metaophiolites belonging to Tozlu formation. Layer thicknesses are between 3–10 m. The carbonates in the rock are completely made of calcite.

Thickness and contact relations

The crystallized limestones belonging to marble member of the Tozlu formation are observed in case of thin levels which show lateral-vertical transition with metaophiolites and amphibolites. The thickness of the crystallized limestones was determined as maximum 100 m.

C. Sarıkız Formation

Definition and spread

It is composed of crystallized limestones with calcschist interlevels. References [10] and [11] stated that all the marbles in the Kazdağ metamorphites represent the same level and are located at the top level of the metamorphites, and the researchers named them “Carbonate formations”. Later, [12] renamed these carbonated formations and gave the name “Sarıkız formation”. These lithologies were named as “Sarıkız marble” by [17]. In this study, these marbles which observe on the Tozlu formation were named as “Sarıkız formation”. Sarıkız formation which show as an arc in the study area is observed in the vicinities Sarıkız Hill, Çatalgedik Hill, Ortaca Hill, Susuz Hill, Kuş Hill, Kovuk Hill, Eğrimermer Hill, İmamyaylası Hill, Yelpezburun Hill and Pınarbaşı Hill (Figure 2).

Lithology and petrography

It is composed of gray-white colored and thin-medium bedded crystallized limestones (Figure 25-a). The calcschist interlevels are sometimes observed within the unit. Crystallized limestones have grain sizes ranging from fine to large. The unit offers densely curved and abundant cracked structures. Abundant secondary calcite veins were observed in the cracks of these metacarbonates. Gneiss nodules up to 3 cm in diameter are observed in crystallized limestones. There is the thin gneiss level at the base of the Sarıkız formation (Figure 25-b). These gneisses which observe up to 5 m thick are yellowish gray colored and abundant micaceous. Foliation and banded structures are quite prominent in gneisses. Reference [25], although not certain, report that there is the base conglomerate (metaconglomerate) derived from metaophiolites below this gneiss level. Reference [24] also indicate that metaconglomerate consisting of gravels derived from metaophiolite is in the bottom of these marbles. In this study, these conglomerates were not found.

Fabric and mineralogy

Calcite ± quartz ± muscovite ± epidote mineral paragenesis was observed in crystallized limestones of Sarıkız formation. These rocks are characterized by massive structures and show granoblastic texture. Calcite crystals make up more than 95% of the crystallized limestones. Calcites are in case of xenoblastic crystals with fine grain sizes ranging from fine to large. Small amount of quartz, muscovite and epidote are observed in the mercacarbonates.

Thickness and contact relations

It is estimated that Sarıkız formation, which shows intense deformation traces as a result of tectonic movements, has a maximum thickness of 600 m in places where the thickest outcrops occur. Sarıkız formation unconformably covers Tozlu formation in the study area. From the top, it is tectonically overlain by Sütüven formation (Figures 2 and 3).

D. Sütüven Formation

Definition and spread

The unit is composed of mica gneisses, sillimanite-biotite gneisses and hornblende-biotite gneisses. These lithologies include amphibolite, marble and granitic gneiss band-lenses and migmatite levels. These lithologies are described was named as Sütüven formation by [17]. Sütüven formation extends over the wide area in the western, northern and eastern parts of the study area. This formation is observed mainly in vicinities of Katmerli Rocks Ubiety, Düden Hill, Karagedik Hill, Harman Hill, Bıçkıbaşı Hill, Tekkaya Hill, Beypınar Hill, Zeybek Hill, Kara Hill, Pazareğrak Hill, Vallaha Hill, Zembikler Ridge, Cızlak Hill, Kılavuz Ridge, Kapıdağ Hill, Kartal Rock Ubiety, Karcıkonağı Hill, Sinekli Hill, Konak Ridge and Kavurmacılar Neighborhood in the study area (Figure 2).

Lithology and petrography

The dominant lithology of Sütüven formation, which is located at the top level of Kazdağ Massif, is composed of gray-dark gray-greenish gray colored and sometimes brownish altered colored mica gneiss, sillimanite-biotite gneiss and hornblende-biotite gneiss (Figure 26). Mica gneisses and biotite gneisses have very evident foliation and medium coarse grains. Very large biotite and feldspar crystals are sometimes observed in these gneisses. Mica gneisses and biotite gneisses contain frequently curved structures and budinage structures due to deformation. Mylonites are observed at the bottom of Sütüven formation due to tectonic movements.

The mica gneisses and biotite gneisses belonging to Sütüven formation have undergone anatexis in some places. Especially, The anatex and migmatite formations which are formed from the gneisses are commonly observed at around Kapıdağ Hill in western part of the study area (Figure 27). Migmatitic gneisses are gray, light gray, whitish in color and fine-medium grained. Paleosome and neosome parts are easily distinguished in these rocks. Folded, ptycmatic, surreitic and nebulitic structures are quite prominent in migmatites (Figure 27). In addition, lit-par-lit, which expresses gneisses indicating transition to migmatites, is observed within the unit. Banded structures are typical in these. Particularly in this region, pegmatitic veins are commonly observed. The pegmatitic veins are form as a result of which light-colored levels of the gneisses melt, later, which the melts crystallize by partly transporting and which the melts are consequently formed a pegmatite-like rock. Also, migmatite formations which are formed from gneisses have been observed in northeast of the Kartal Rock which is located to the east of the study area and in the northwest of Düden Hill.

Fig. 25. a) *Thin-medium bedded crystallized limestones belonging to Sarıkız formation observed at southeast of Düden Hill,* ***b)*** *Crystallized limestones and gneisses which are located below of the crystallized limestones observed at the bottom level of the Sarıkız formation at northwest of İmamyaylası Hill (the gneiss is the place where geologist attractive is located)*

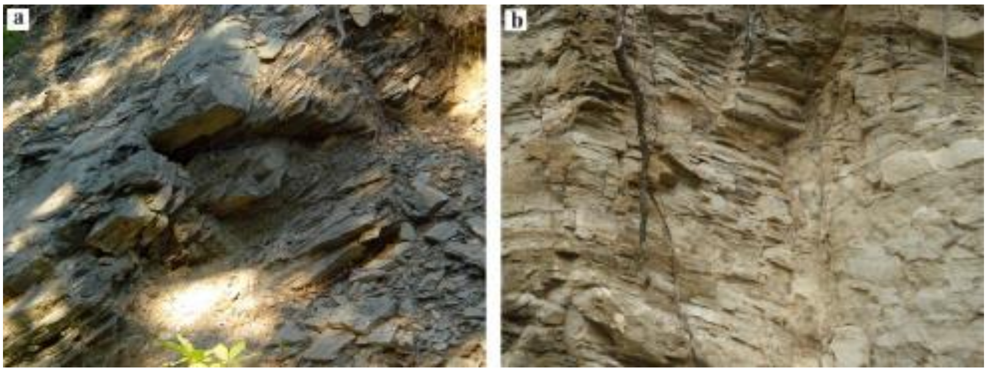

Fig. 26. Mica gneisses and biotite gneisses belongingto Sütüven formation observed in northeast of Kartal Rock (b) and in west of Düden Tepe (a)

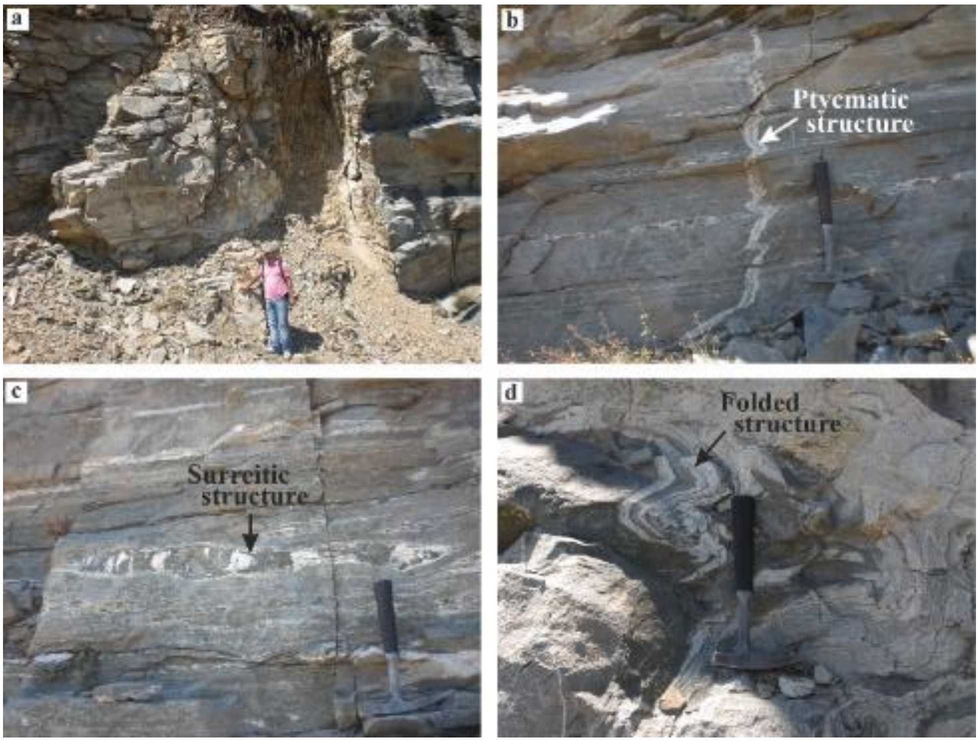

Fig. 27. a) Partial anatexis and migmatite formations in mica gneisses, b) ptycmatic migmatites formed from sillimanite-biotite gneisses, c) Surreitic migmatites formed from sillimanite-biotite gneisses and d) Migmatite formations formed from mica gneisses observed in the vicinity of Kapıdağ Hill

Crystallized limestone interlevels are observed in the gneisses belonging to Sütüven formation. Gneisses sometimes alternate with these metacarbonates. These crystallized limestones are milky white colored, thin-medium bedded and fine grained. The amphibolite band-lenses observed in the gneisses are dark gray-blackish in color and massive. In amphibolites, black colored and prismatic hornblende crystals and grayish white colored feldspar are easily distinguished.

In the mica gneisses and biotite gneisses of Sütüven formation, gray - white colored, medium grained granitic gneisses are observed. Granitic gneisses are quite hard and massive. Granitic gneisses are commonly observed around Karagedik Hill, Harman Hill and Bıçkıbaşı Hill especially in the northwest of the study area. Biotite, feldspar and sometimes garnet crystals are prominent in granitic gneisses.

Fabric and mineralogy

Plagioclase (albite-oligoclase-andesin) + quartz ± orthoclase + biotite (brown and green) ± sillimanite + hornblend (tschermakite) ± garnet (prop-almandine-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, penninite-clinochlore) + muscovite ± kyanite ± calcite ± staurolite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite are observed in **mica gneiss, sillimanite-biotite gneiss** and **hornblende-biotite gneiss** belonging to Sütüven formation. These rocks are characterized by porphyroblastic and granolepidoblastic textures. *Hornblende (tschermakite) + plagioclase (albite-oligoclase-andesine) ± biotite (brown) ± quartz ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, pennin-clinochlore) + sphene* mineral assemblage are observed **amphibolites** observed as interlevels in the gneisses. Amphibolites show nematoblastic texture.

Feldspars; are observed as plagioclase and orthoclase in gneisses and amphibolites. ***Plagioclases*** are in case of subidioblastic and xenoblastic crystals. They is sometimes seen as porphyroblast in gneisses. Muscovite, brown colored biotite, epidote, chlorite, quartz and opaque mineral inclusions are observed in plagioclase porphyroblasts in gneisses. Muscovite, brown biotite, epidote, chlorite, quartz inclusions in these plagioclase porphyroblasts surrounded by the S_2 foliation plane formed by brown biotite, muscovite and tschermakite form the S_1 foliation plane of the rock (Figure 28-a).

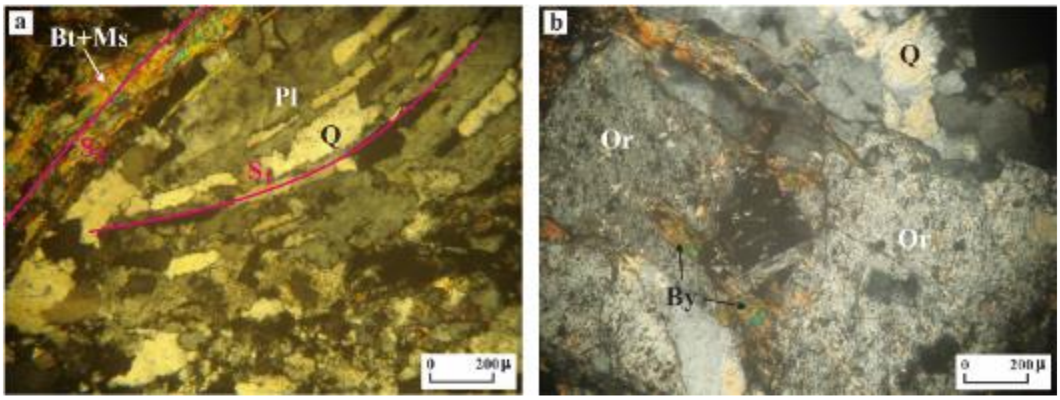

Fig. 28. Mica gneisses belonging to Sütüven formation. a) Plagioclase (P1) porphyroblast containing quartz (Q) inclusions extending in one direction forming S_1 foliation and surrounded by S_2 foliation. b) Orthoclase (Or) which turn to sericite and biotites (Bt) forming S_2 foliation. Ms: Muscovite, // Nicol

Therefore, these plagioclases crystallized pretectonically according to the F_2 deformation stage. Muscovite, brown colored biotite, epidote, chlorite forming S_1 foliation is the first stage metamorphism product formed under amphibolite facies conditions with high pressure and low temperature. According to the extinction angle determination, plagioclases are in the composition of albite ($Ab_{95}An_{05}$), oligoclas ($Ab_{76}An_{24}$, $Ab_{74}An_{26}$) and andezin ($Ab_{66}An_{34}$, $Ab_{62}An_{38}$). Myrmekitic textured plagioclases are observed in gneiss. ***Orthoclases*** are xenoblastic and show karlsbad twin and abundant inclusions (Figure 28-b). Orthoclases is sometimes seen as porphyroblast in gneiss. Orthoclases and plagioclases in both gneisses and amphibolites were turned to sericite by retrogressive metamorphism (Figure 28-b).

Micas; is observed as biotite and muscovite in gneiss. Biotite is observed less than 10% in amphibolites. ***Biotites*** are plaquely shaped and brown-green in color. Brown colored biotites have been aligned both parallel to the S_1 foliation plane with muscovite, epidote, chlorite and quartz, and parallel to the S_2 foliation plane with muscovite and tschermakite (Figure 28-a). Therefore, these biotites wewe formed under amphibolite facies conditions. The brown colored biotites in the sillimanite-biotite gneisses were transformed into sillimanite and possibly kyanite by progressive metamorphism (Figures 29 and 30). In the gneisses and amphibolites, they is transformed into partially or completely chlorite (ripidolite-picnochlorite) by retrogressive metamorphism (Figure 29). ***Muscovite*** is plaquely shaped. Muscovites commonly shown in mica gneisses are observed in parallel to S_2 foliation planes (Figure 28-a). In addition, they forms S_1 foliation extending in one direction within plagioclase porphyroblasts in these rocks.

Sillimanite; are in case of fibrous shaped crystals (Figures 29 and 30). The fibrous sillimanite crystals observed in mica gneisses and biotite gneisses have been aligned parallel to the S_2 foliation plane formed by biotite and muscovite. Sillimanites were exposed by progressive reactions from biotite under the conditions of second metamorphism in upper amphibolite facies developed after the first stage metamorphism developed in amphibolite facies in high pressure areas of middle temperature metamorphism (Figures 29 and 30). It is observed in all gneisses together with orthoclase.

Staurolite; is observed in sillimanite-biotite gneisses. Staurolites are shown as generally prismatic crystals (Figure 31). They are typical with their yellow colors, parallel extinctions and sometimes including quartz inclusions. Staurolites were formed under the conditions of amphibolite facies in high pressure areas of middle temperature metamorphism which is the first stage metamorphism. In particular, the presence of staurolite together with kyanite and sillimanite in the sillimanite-biotite gneisses shows that the staurolites are preserved in the second stage of metamorphism under the conditions of upper amphibolite facies due to Barrow type decreasing pressure - increasing temperature (progressive metamorphism) in environment. Garnet and/or kyanite have been transformed into staurolite by progressive reactions (increasing temperature) in environment.

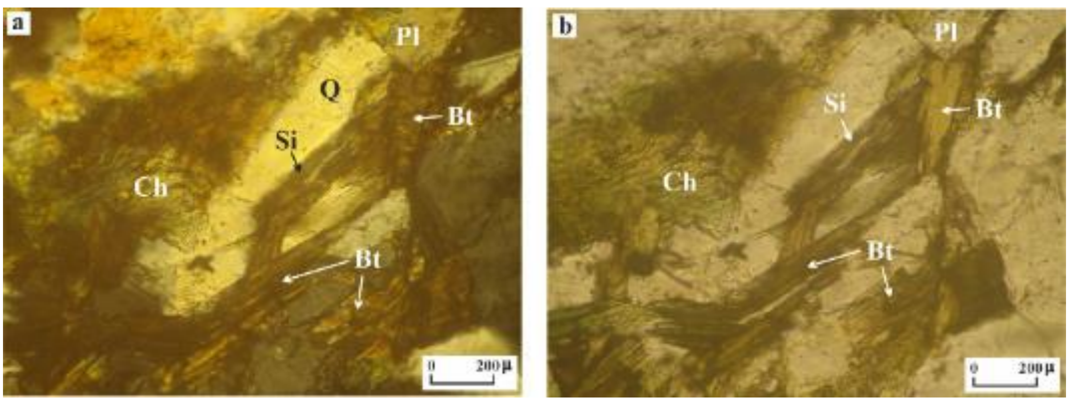

Fig. 29. Biotite (Bt), fibrous sillimanite (Si) which is formed from biotite, chlorite (Ch) which is formed from biotite, plagioclase (Pl) and quartz (Q) observed in sillimanite-biotite-gneiss belonging to Sütüven formation, a) // Nicol, b) / Nicol

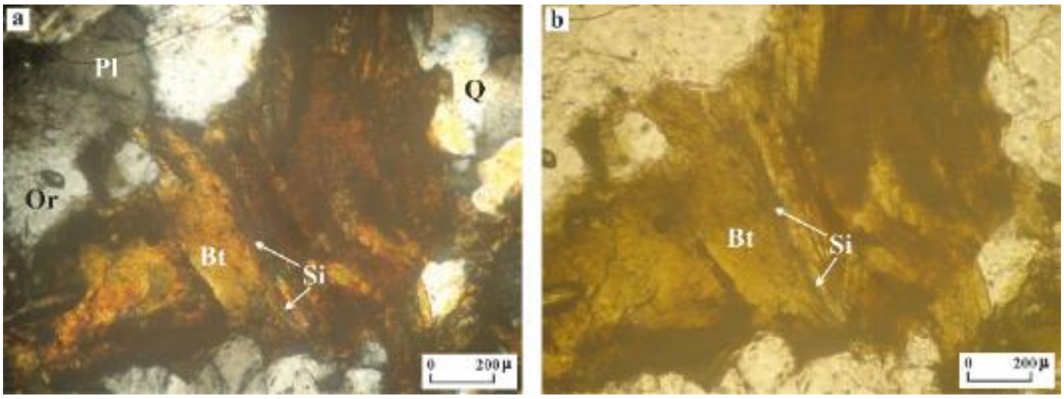

Fig. 30. Biotite (Bt) and fibrous sillimanite (Si) which is transformed into biotite observed in sillimanite-biotite-gneiss belonging to Sütüven formation. Or: orthoclase, Pl: Plagioclase and Q: Quartz, a) // Nicol, b) / Nicol

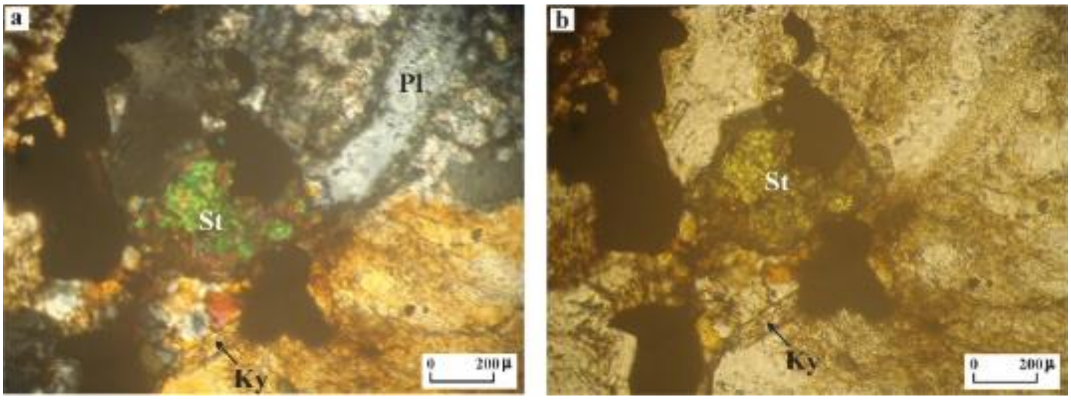

Fig. 31. Staurolite (St), kyanite (Ky) and plagioclase (Pl) observed in sillimanite-biotite gneiss belonging to Sütüven formation, a) // Nicol, b) / Nicol

Kyanite; are generally in case of subidioblastic long prismatic crystals in gneisses (Figure 31). It show low angled oblique extinction (3^{o} - 8^{o}) and high relief, and it has bi-directional cleavages. Kyanite is in the form of long prismatic crystals in parallel to the platy biotites that form the S_2 foliation in sillimanite-biotite gneisses. This indicates that kyanite are also syntectonic according to F_2 deformation phase. Thus, kyanites were exposed by progressive reactions from biotite and possibly staurolite after the amphibolite facies conditions in the high pressure areas of middle temperature metamorphism which is the first stage metamorphism. The presence of kyanite and sillimanite together in sillimanite-biotite gneisses shows that kyanite was still preserved under the conditions of the second stage metamorphism which is formed at the upper amphibolite facies.

Garnet; is in case of colorless - pale brownish yellow colored and xenoblastic-subidioblastic prismatic crystals in gneiss. Rarely it is shown as porphyroblast. Garnets were transformed into chlorite (ripidolite) from edges by the retrogressive metamorphism in the greenschist facies which is observed as the last metamorphism at the Kazdağ Massif.

Hornblende; forms the main component of the amphibolite (Figure 32-a). It is observed up to 8% in hornblende-biotite gneisses. Hornblendes observed in these rocks are generally long prismatic shaped and brown-greenish brown colored. It shows low angled oblique extinction between 16^{o}-23^{o}. Hornblendes with these properties are probably in composition "tschermakite". It is observed as long prismatic crystals arranged parallel to S_2 foliation in hornblende-biotite gneisses. For this reason, it is thought that tschermakites are exposed under the conditions of upper amphibolite facies at high temperature which are observed as second stage metamorphism in Kazdağı Massif. Tschermakites are transformed into chlorite from their crystal edges.

Chlorite; Two different formations of chlorites are observed in gneisses. One of these is Mg-chlorite forming the S_1 foliation plane together with muscovite, brown biotite, epidote and quartz in the plagioclase porphyroblasts. These chlorites are abnormal brown birefringence colored and pale green colored. They are probably in "penine-clinochlorine" composition. Mg-chlorites must have been exposed by the first stage metamorphism. Other chlorite is chlorite which is the last stage metamorphism product and which is formed by the retrogressive metamorphism in greenschist facies from garnet, biotite and hornblende. These are Mg-Fe chlorites (ripidolite-picnochlorites) which are green colored, abnormal brown birefringence colored and leafy shaped (Figure 32-b). Mg-Fe chlorites are also observed in amphibolites.

The minerals and percentage values of these minerals observed in six samples belonging to mica gneiss, sillimanite-biotite gneiss, hornblende-biotite gneiss and amphibolite observed in Sütüven formation are given in Table 4.

Thickness and contact relations

Sütüven formation is located with a tectonic contact on Sarıkız formation in most of the study area. It is observed with a tectonic contact on the Tozlu formation in the south of Düden Hill and in the vicinity of Aktaş Hill. It is observed with a tectonic contact on the Fındıklı formation in the vicinity of the Katmerli Rocks (Figure 2). The upper surface of Sütüven formation could not be observed in the study area. Outside the study area, it is cut by Oligo-Miocene aged granitoids from the top [25].

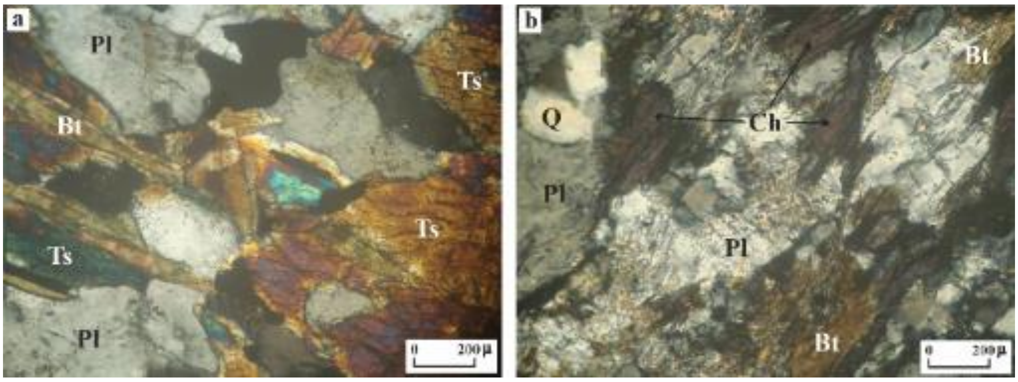

Fig. 32. Amphibolite (a) and sillimanite-biotite gneiss (b) belonging to Sütüven formation. Çe: Tschermakite, Bt: Biotite, Pl: Plagioclase, Ch: Mg-Fe chlorite which is transformed into biotite, Pl: Plagioclase and Q: Quartz, // Nicol

Table 4. The components, % values of the components and rock names of six samples belonging to mica gneiss, sillimanite-biotite gneiss, hornblende-biotite gneiss and amphibolite

The Name of Mineral	**The Name of Rock**					
	Mica gneiss	**Mica gneiss**	**Sillimanite-biotite gneiss**	**Sillimanite-biotite gneiss**	**Hornblende-biotite gneiss**	**Amphibolite**
Quartz	15	19	20	18	19	3
Plagioclase	12	10	13	10	12	28
Orthoclase	10	8	8	11	8	3
Muscovite	10	20	-	-	-	-
Biotite	24	24	34	33	36	8
Hornblende	-	-	-	-	8	50
Garnet	4	-	2	3	-	-
Kyanite	2	2	3	4	-	-
Staurolite	-	-	4	2	-	-
Sillimanite	2	3	7	6	-	-
Epidote	3	2	2	2	3	2
Zoisite/Clinozoisite	2	-	-	1	2	-
Chlorite	11	8	4	6	8	5
Microcline	2	3	-	-	1	-
Tourmaline	1	-	1	1	1	-
Rutile	-	-	-	1	-	-
Apatite	1	-	1	1	1	-
Sphene	1	1	1	1	1	1
TOTAL	100	100	100	100	100	100

Besides, outside the study area, it is also tectonic contact with strike-slip and detachment faults with Upper Paleozoic and Miocene aged units from the top [25]. The Sütüven formation, which is limited to the tectonic contact from the bottom and whose upper surface cannot be observed in the study area, has a thickness of approximately 1500 m.

D.1. Granitic gneiss member

Definition and spread

The granitic gneisses observed as bands and lenses within the gneisses of Sütüven formation are mapped to the mappable scale in the formation and are examined as “granitic gneiss member” within the Sütüven formation. The unit is defined as “granitic gneiss” within Sütüven formation by [24] and [25]. Granitic gneiss member is observed in a narrow area around Kocayatak Tepe in the northwest of the study area (Figure 2).

Lithology and petrography

Granitic gneisses are white-gray-dark gray in color. Black colored and prismatic hornblendes, black and platy biotites, and quartzs, plagioclases and orthoclases from light colored minerals are very prominent in the unit. It is quite hard and generally massive. In contrast, hornblendes in granitic gneisses are aligned in the same direction with foliation of mica gneisses and biotite gneisses belonging to Sütüven formation (Figure 33). This shows that granitic gneisses settled in the area before the last metamorphism observed in the Kazdağ Massif and later undergone metamorphism with mica gneisses and biotite gneisses belonging to Sütüven formation. In the study area, metaaplite veins which are in 2-5m thick are observed in some locations within the granitic gneisses.

Fig. 33. Granitic gneisses observed in southwest (a) and in south (b) of Kocayatak Hill. In the granitic gneiss, the indistinct foliation is observed (a). c) Foliated structure in granitic gneiss observed in southwest of Kocayatak Hill

Metaaplites are white-light gray colored and fine-medium grained. In these metaaplites, foliations and lineations can be distinguished, although not very prominent.

Fabric and mineralogy

*Plagioclase (albite-oligoclase-andesin) + orthoclase + quartz + biotite (brown) ± hornblende (tschermakite) + garnet ± chlorite (ripidolite-*picnochlorite*, pennin-clinochloride) ± epidote ± zoisite / clinozoisite + sphene ± rutile ± apatite* mineral assemblage is observed in **granitic gneisses**. These rocks are granoblastic in texture.

Feldspars*;** are observed as **plagioclase** and orthoclase in granitic gneisses. ***Plagioclases are generally in the form of subidioblastic and twining crystals (Figures 34-a, c and d). It is sometimes observed as porphyroblast. Mirmecitic texture is observed in some plagioclases. According to the extinction angle determination, plagioclases are in the composition of albite ($Ab_{92}An_{08}$, $Ab_{94}An_{06}$), oligoclas ($Ab_{75}An_{25}$, $Ab_{77}An_{23}$) and andezin ($Ab_{67}An_{33}$, $Ab_{69}An_{31}$). ***Orthoclases*** are generally xenoblastic and show abundant inclusion and sometimes karlsbad twin (Figure 34). Plagioclases and orthoclases sometimes were transformed into sericite.

***Biotite*;** show brown colors and platy shapes. Biotites were partially or completely transformed into chlorite (ripidolite-picnochlorite) (Figure 34-d).

***Hornblende*;** is long-short prismatic shaped and brownish green colored and show low angled oblique extinction between 16º-20º (Figures 35-a and b). With these properties, hornblendes are in "tschermakite" composition. It is observed up to 20% in granitic gneiss samples. Hornblendes have been transformed into chlorite and sometimes actinolite from the crystal edges.

***Garnet*;** is observed up to 5% in some granitic gneisses. Garnets are colorless - pale brownish yellow colored and in case of usually xenoblastic sometimes subidioblastic prismatic crystals (Figures 35-c and d). Some garnet crystals were transformed into chlorite (ripidolite) from their edges.

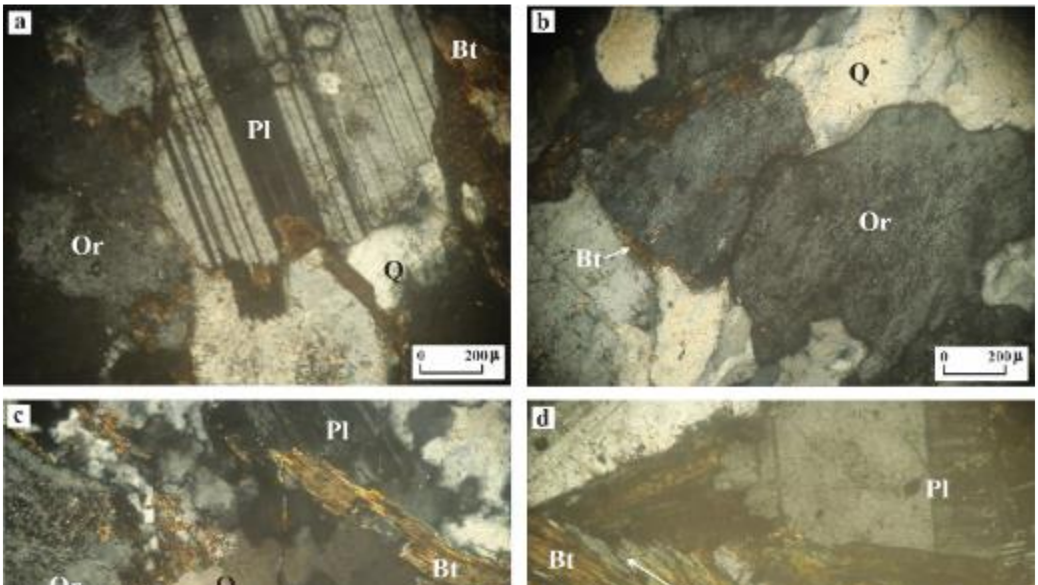

Fig. 34. Plagioclase (P1), orthoclase (Or), quartz (Q), biotite (Bt) and chlorite which is transformed into biotite (Ch) observed in granitic gneisses, // Nicol

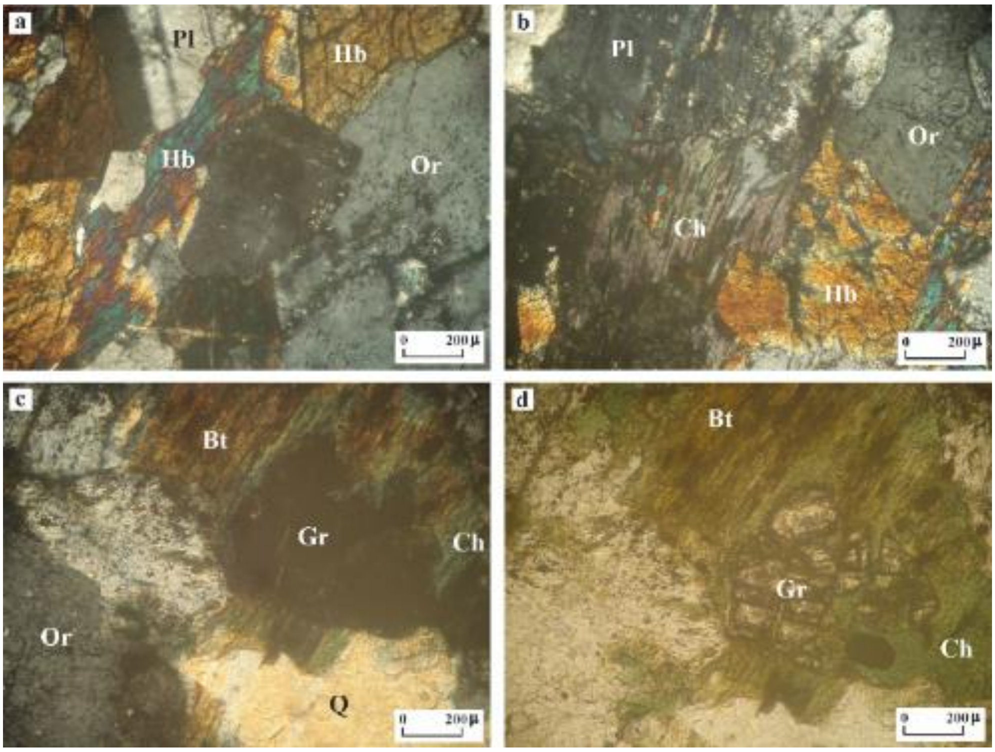

Fig. 35. Hornblende (Hb), orthoclase (Or), plagioclase (P1), garnet (Gr), biotite (Bt), chlorite (Ch) which is transformed into biotite and garnet and quartz (Q) observed in granitic gneisses, a, b and c) // Nicol, d) / Nicol

The minerals and percentage values of the minerals determined in the three samples belonging to granitic gneisses are given in Table 5.

Table 5. The components, % values of these components and rock names of three samples belonging to granitic gneisses

The Name of Mineral	The Name of Rock		
	Granitic gneiss	**Granitic gneiss**	**Granitic gneiss**
Quartz	24	20	23
Plagioclase	20	13	20
Orthoclase	28	34	26
Biotite	16	6	5
Hornblende	-	20	12
Garnet	2	-	5
Epidote	1	2	1
Zoisite/ Clinozoisite	-	1	1
Chlorite	7	5	4
Rutile	1	-	1
Apatite	-	1	1
Sphene	1	-	1
TOTAL	100	100	100

Thickness and contact relations

Granitic gneisses area are about 400 m thick in the study. Granitic gneisses were initially located in the area by cutting mica gneisses and biotite gneisses belonging to Sütüven formation. Later, both orthogneisses and paragneisses were metamorphosed together in the Kazdağ Massif. With this metamorphism, orthogneisses gained foliation and lineation in the same direction with the foliation observed in paragneisses. Granitic gneisses are also observed as interlevels, which are size can't map, in mica gneisses and biotite gneisses which constitute the dominant lithology of Sütüven formation.

IV. DISCUSSION

In this study, it is aimed to determine the stratigraphic properties of the Kazdağ Massif metamorphics exposed in the region and to investigate the petrographic properties of these metamorphites exposed to polymetamorphism. Reference [12] described the Kazdağ Massif from the aged to the young as the Tozlu formation consisting of serpentinized dunites, amphibolites and layered metagabbros and the Bozağaç Tepe formation consisting of gneisses and the Sarıkız formation made of marbles. Reference [13] has been reported that the units named as the Kazdağ Group in the region underwent the metamorphism at amphibolite and greenschist facies. The researchers said that the amphibolite facies consist of migmatite, sillimanite and staurolite gneiss, biotite gneiss, biotite-amphibole gneiss, amphibole gneiss and that micaceous quartz schist, marble, muscovite-calcschist, sericite-muscovite-quartz schist, epidote-actinolite-chlorite schist, tremolite-actinolite serpentinite, profillite-calcschist, biotite-chlorite schist, quartz-muscovite-sericite schist, metaclays, marble, phyllite. graphite schist, epidote-chlorite-actinolite marble, quartz-epidote-chlorite schist, epidot-muscovite-albite-chlorite schist, quartz schist and marble were observed at greenschist facies. Reference [17] contradistinguished the Kazdağ Massif metamorphites as Fındıklı formation, Tozlu formation, Sarıkız Marble and Sütüven formation from bottom to top. In this study, it was determined that the Kazdağ Massif consisted of three separate nappes with tectonic contacts. These are the lower nappe units forming Fındıklı formation, the middle nappe units forming the Tozlu and Sarıkız formations and the upper nappe units forming Sütüven formation from bottom to top.

References [10], [11] and [13] suggested that Kazdağ metamorphites underwent the metamorphism at greenschist and amphibolite facies. Reference [14] suggested that the gneisses in the Kazdağ massif contained staurolite, kyanite and silimanite and that the massif underwent metamorphism at the amphibolite facies. He also stated that metaophiolites are present in the region and that they are metamorphosed at amphibolite facies. Reference [20] stated that the metagabbros observed in metaophiolitic rocks belonging to Kazdağ massif underwent metamorphism at amphibolite facies under ~ 660 ºC temperature and ~ 10 kbar pressure conditions. The researcher states that metaophiolitic rocks are separate tectonic slices with higher pressure in Kazdağ Massif. In this study, it were detected three phase metamorphism in the Kazdağ Massif, which was subjected to multi-stage deformations in relation to intense tectonic movements. These stages of metamorphism are very prominent in metapelitic, metasemipelitic and metabasic rocks of Fındıklı and Sütüven formations.

V. CONCLUSION

In study area is located Kazdağ Massif, which is probably of Paleozoic primitive age is completely metamorphic. The Kazdağ Massif consists of three separate nappes with tectonic contacts. These are the lower nappe units forming Fındıklı formation, the middle nappe units forming Tozlu and Sarıkız formations and the upper nappe units forming Sütüven formation ,from bottom to top. Fındıklı formation is composed of hornblende gneiss, biotite-hornblende gneiss, epidote-hornblende gneiss, epidote-biotite gneiss, garnet-biotite gneiss, garnet-hornblende gneiss, kyanite-garnet-micaschist and kyanite-garnet-biotite schist. These amphibole-biotite gneisses and mica schists-biotite schists show alternation with crystallized limestones that form Altınoluk marble member. At the top level of the Fındıklı formation, there are large crystalline crystallized limestones (Babadağ marble member). Tozlu formation consists of amphibolite member consisting of amphibolites and amphibol schists which show lateral-vertical transitive with each other and metaophiolite member consisting of metadunite, metaproxenite, metaproxenhornblendite and serpentinites and marble member consisting of crystallized limestones. The Sarıkız formation, which is unconformably observed on the Tozlu formation, starts with a thin gneiss level at the bottom, and at the top, thick crystallized limestones which contain calcschist interlevels is observed. Sütüven formation is composed of mica gneiss, sillimanite-biotite gneiss and hornblende-biotite gneiss including amphibolite, granitic gneiss and marble bands and lenses. Migmatite formations are observed in places within the unit. Granitic gneisses in the Sütüven formation have been distinguished as granitic gneiss member.

Hornblende (tschermakite, edenit and barroisite) + plagioclase (albite-oligoclase-andesin) + quartz ± orthoclase + biotite (brown, green) + garnet (prop-almandin-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, pennin-clinochlorine) ± kyanite ± staurolite + muscovite ± calcite ± sillimanite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite are observed in amphibole and biotite gneisses belonging to Fındıklı formation. Kyanite-garnet-mica schists and kyanite-garnet-biotite schists belonging to Fındıklı formation include *biotite (brown) + quartz + garnet (prop-almandine-grossular) + kyanite + sillimanite + plagioclase (albite-oligoclase-andesin) ± muscovite + chlorite (ripidolite-picnoclorite - pennin-clinochloride) ± epidote ± zoisite / clinozoiside ± orthoclase + tourmaline (green) ± sphene ± rutile ± apatite* mineral assemblages.

Mica gneisses, sillimanite-biotite gneisses and hornblende-biotite gneisses which form the dominant lithologies of Sütüven formation include *plagioclase (albite-oligoclase-andesine) + quartz ± orthoclase + biotite (brown and green) ± sillimanite + hornblende (tschermakite) + garnet (prop-almandin-grossular) ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, pennin-clinochloride) + muscovite ± kyanite ± calcite ± staurolite ± microcline + tourmaline (green, brown) + sphene ± rutile ± apatite* mineral assemblage. Amphibolites belonging to Sütüven formation are characterized by *hornblende (tschermakite) + plagioclase (albite-oligoclas-andesine) ± biotite (brown) ± quartz ± epidote ± zoisite / clinozoisite ± chlorite (ripidolite-picnochlorite, pennin-clinochlor) + sphene* mineral assemblage *Plagioclase (albite-oligoclas-andesin) + orthoclase + quartz + biotite (brown) ± hornblende (tschermakite) + garnet (prop-almandine-grossular) ± chlorite (ripidolite-picnochlorite, pennin-clinochlorine) ± epidote ± zoisite / clinozoisite + sphene ± rutile ± apatite* mineral assemblage is observed in granitic gneisses belonging to Sütüven formation.

In metapelitic, metasemipelitic and metabasic rocks observed in Fındıklı and Sütüven formations, that both mineral paragenesis and index minerals exposed under different metamorphism conditions observe and the massive is exposet to multi-stage metamorphism by intense tectonic movements show that the massive underwent to the metamorphism at least three stages.

ACKNOWLEDGMENT

This study was prepared by using the project numbered 10201139 supported by Selçuk University Scientific Research Projects Coordination Unit.

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